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*Egyptian Journal of Forensic Sciences* (2022) 12:41
https://doi.org/10.1186/s41935-022-00298-y

Egyptian Journal of Forensic Sciences

ORIGINAL ARTICLE Open Access

# Evaluating costal cartilage for sex and age estimation from PA chest radiographs of North Indian population: a retrospective study

Shama Patyal[1] and Tejasvi Bhatia[2*]

## Abstract

**Background:** This study is conducted to estimate age and sex from chest radiographs. The aim of this study was to determine (I) whether costal cartilage calcification pattern help in estimating sex in North Indian sample and (ii) whether there is any relation between age and costal cartilage calcification.

**Results:** The statistical probability of estimating peripheral pattern in male was 99.3%, and for females, it was 100% for central type of calcification. The minimum age where lower costal calcification was present was 22-year-old female and 21 years old male. The degree of calcification and age showed positive correlation; similarly, the value of spearman's rho showed significant result (for whole sample $r_s = 0.911$, $p < 0.01$ (for male subjects, it was $r_s = 0.921$, $p < 0.01$; for females, it was $r_s = 0.905$, $p < 0.01$)).

**Conclusions:** The degree of calcification is useful in estimating age groups and becomes more determined with advancing age. Prediction of sex by using radiological method gives the advantages of simplicity, inexpensiveness, speed, and high accuracy. This method for age and sex estimation will play a useful role in screening test and in cases where the thoracic part of the body is found like dismembered body, putrefied dead remains, and unidentified bodies.

**Keywords:** Chest radiographs, Calcification, Ossification, Age estimation, Sexual dimorphism

## Background

For purpose of human identification, different methods are provided in forensic anthropology, using different bones like pelvic bones, skull hands, and wrist bones (Krishan et al., 2016a, b, c). After the pelvis, the best anatomical areas to sex estimates is not the skull anymore but the long bones (Klales, 2020a, b, c). In case recently dismembered remains are available, then costal cartilage (CC) calcification can be useful in establishing the age and sex. The human thoracic region is relatively important in biological and forensic studies as it is active between adolescent growth and adult maturational and degenerative periods. Most anthropological methods for handling situations of questionable identity are developed to be used on dry bone and, at the very least, require a partially or totally defleshed body. While all individuals requiring a forensic examination are in some stage of decomposition, within the majority of situations, these bodies are relatively intact. In such instances, it is going to be an easy procedure to initiate identification processes using fingerprints, visual confirmation, unique physical characteristics, dental records, or past medical procedures as evidence (de Boer et al., 2020a, b, c). However, in certain circumstances, the private parts may be too decomposed to use these techniques, or ante-mortem medical and/or dental records may be incomplete, inaccessible, or difficult to obtain. Thus, for the purpose of sex and age estimation, radiodiagnosis or forensic

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radiology plays a key role as it provides fast, easy, and cost-effective methods with the help of modalities like X-ray machines and CT computed tomography (Patyal and Tejasvi, 2021). Chest X-ray radiographs are routinely used in the radiology department for routine investigations. Estimation of sex from radiographs on behalf of the shadow of mammary glands is easy but not possible in case of putrefied body or in case of dismembered body. The age estimation from costal cartilage will be useful in the state of Himachal Pradesh (North India) as it is a hilly area and unidentified dead remains are usually recovered from the ditches.

Costal cartilage is present on the anterior wall of the chest and connects the sternum to the ribs. CC becomes visible on a radiograph once they start calcifying. Calcification and ossification are the changes associated with increasing age. Fischer (1955a, b, c) was the first to propose the sex-related pattern, and he concluded the role of endocrine on hyaline calcification. Later, Elkeles (1966a, b, c) and McCormick et al. (1985a, b, c) also confirmed the presence of sexual dimorphism in calcification pattern of CC. In 2015, they studied a sample of the Scottish population (Middleham et al., 2015a, b, c). Forty-one cadavers (22 male and 19) aged 57–96 years were studied by two different methods given by Mc Cormick et al. and Rejtarova et al. and stated that with Mc Cormick, 82.4% of males were correctly sexed but only 41.2% of females. They used a new method based on whether calcified deposits were trabecular bone or sclerotic calcified deposits. Earlier studies associate the calcification of CC to diseases like pulmonary diseases, atherosclerosis, dietary problems, and metabolic or endocrine disorders. But King in his study confirmed that calcification was not related to diseases (King, 1939a, b, c). Genetic influence on homozygotic twins showed the presence of a similar type of calcification pattern as studied by (Vastine 2nd et al., 1948a, b, c).

Yaşar İşcan et al. (1984a, b, c) showed age related changes while studying CC of fourth rib (Yaşar İşcan et al., 1984a, b, c); later, Inoi (1997a, b, c), Dedouit et al. (2008a, b, c), and Fanton et al. (2010a, b, c) also studied the fourth rib for age estimation. While King in 1939 and later on other authors Kampen et al. (1995a, b, c), Barchilon et al., 1996a, b, c) analysed first rib CC for estimation of age. The authors have analysed the process of calcification of first rib by methods like osteology and biochemical (King, 1939a, b, c; Semine and Damon, 1975a, b, c; Barchilon et al., 1996a, b, c). They stated that ossification of the first rib is a real process. So, in this study, we will study the calcification for the first rib regarding age estimation and calcification of the lower ribs for sex estimation. In this process, respiratory stress seems to be the main cause of calcification of the first rib, whereas in the lower ribs, chest expansion seems to be the main cause of calcification. Stage of calcification were evaluated on the basis of age and sex. Spearman's rho correlation was used to evaluate the relationship between age and level of calcification. Chi-square test was carried out to check the independence of type of CC and sex. Predictive values for type of CC were calculated using statistical analysis.

Our study aim is to determine (I) whether costal cartilage calcification pattern help in estimating sex in North Indian sample and (ii) whether there is any relation between age and costal cartilage calcification.

## Methods

This was a retrospective study conducted in the state of Himachal Pradesh. Chest PA (posterior-anterior) radiographs of routine healthy patients were taken. Radiographs of patients which were reported normal in the time span of 1 year (2020 to 2021) by the radiologist were taken into the account. Ethical permission was taken before conducting the study. A total 450 PA radiographs were taken from the Dr. Radhakrishnan Government Medical College Hamirpur. The radiographs were digital in their format, and the software Image works (IW) helped in zooming and viewing the radiographs on the monitor; we could also be able to enhance the contrast whenever required with the help of software, thus helping making this study cost-effective as we need not to take hard copies of radiographs and no repeats of radiographs.

The radiographs were divided into seven age groups: 0–20, 21–30, 31–40, 41–50, 51–60, 61–70, and 71 and above. The aim of our study was to estimate age and sex from the costal cartilage. For estimating age, we were considering CC of first rib of right side, and for sex estimation, we will consider the ribs other than first. The past number of studies has shown that sex is not related to first CC calcification, whereas the lower rib cartilage showed sexual dimorphism.

The aim of the study depends upon following attributes:

- The pattern of calcification of cartilage (costal) for estimation of sex
- The degree of calcification of cartilage (costal) for age estimation

All the samples for the study compromise of the Indian population, who visited the hospital during 2020–2021. Normal radiographs of subjects were considered so that the process of calcification would not be hindered, and it would not affect the final result of the study.

For sex estimation, we divided the calcification pattern broadly as described by Rejtarová et al. (2004a, b, c).

- Peripheral—where calcification presents on inferior or superior margins of cartilage
- Central—where calcification mainly presents on the central part of cartilage
- Mixed—combination of above two (peripheral and central)
- Indifferent—calcification pattern which cannot be distinct into any above category

For age estimation, we consider the degree of calcification of cartilage as used by Michelson (1934a, b, c):

- Stage 0—No calcification
- Stage 1—Recent onset of calcification
- Stage 2—Calcification less than 50% of total
- Stage 3—Calcification more than 50% or complete

The stage of calcification was measured as a ratio between the maximum calcification area and the total area from cartilage to the rib attachment of the right side. All the measurements were carried out by two highly experienced radiographers with the help of the IW software, and whenever there was doubt, the opinion of the senior radiologist was taken as final. The type of calcification and stages of calcification can be understood easily by the radiographs of subjects encountered during this study in PA projection given in Figs. 1, 2, and 3.

### Inclusion and exclusion criteria

The inclusion criteria were as follows: normal posterior-anterior chest X-ray of both sexes will be considered for the estimation. The exclusion criteria were as follows: normal posterior-anterior chests X-ray with any

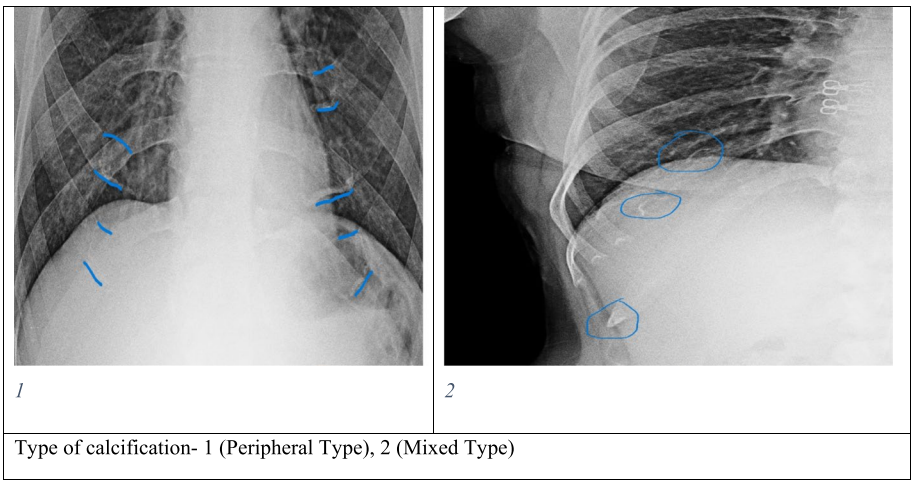



**Fig. 1** Pattern of calcification

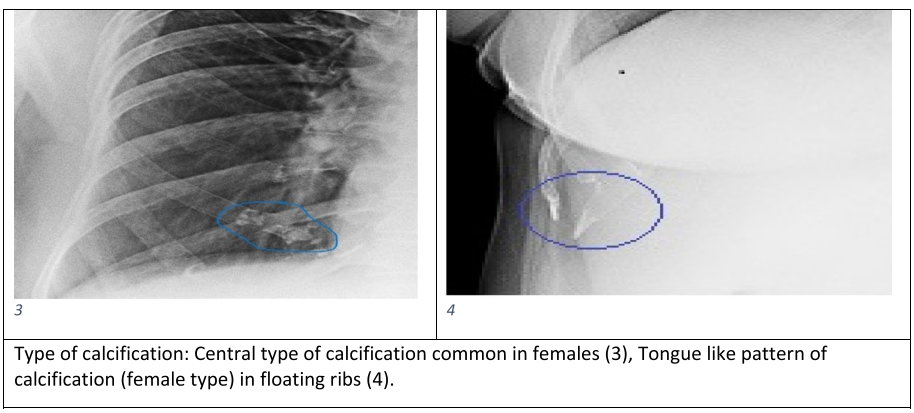
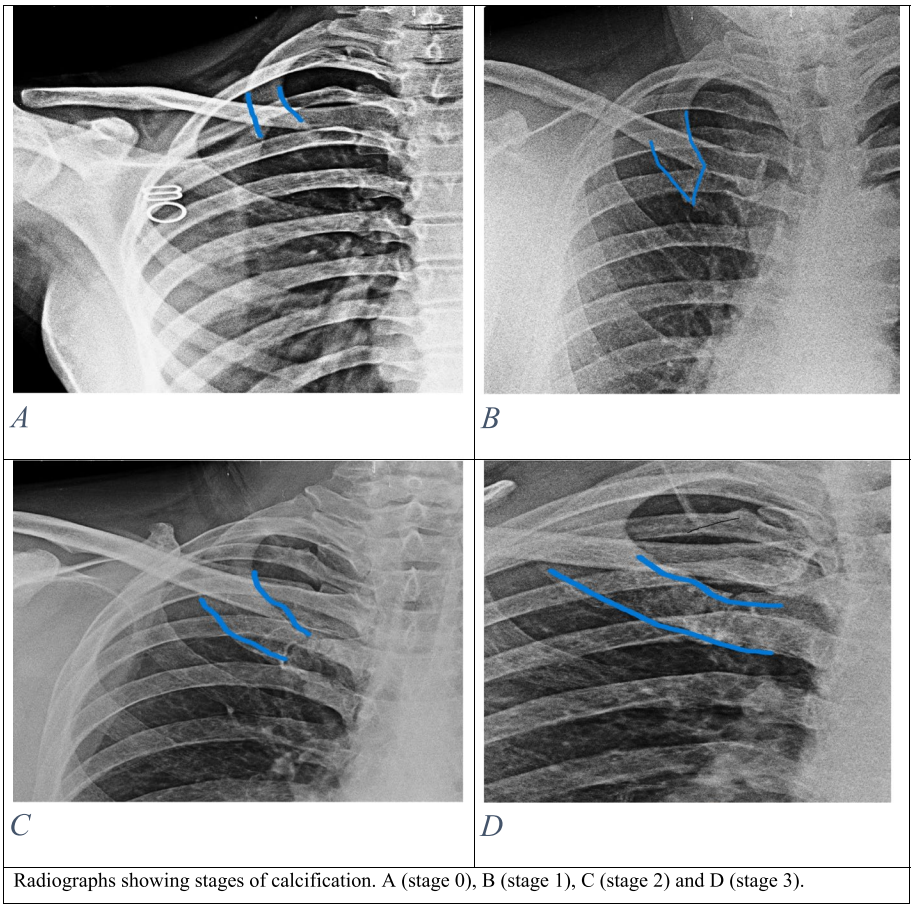



**Fig. 2** Central type—calcification pattern common in females




Radiographs showing stages of calcification. A (stage 0), B (stage 1), C (stage 2) and D (stage 3).

**Fig. 3** Calcification stages

deformity, cardiovascular disease or degeneration, and trauma to thorax.

### Sampling technique

In this study, posterior-anterior chest radiographs of subjects having age 5 years to 70 and above years that will be reported normal will be randomly selected from the radiology department. The radiographs will be divided into seven groups of age range as described above.

### Equipment

The equipment used is as follows: X-ray plant for taking X-ray of the subjects. FCR PRIMA CONSOLE and IMAGE WORKS of Fujifilm.

### Sample position and technique

#### *Posterior-anterior (PA) erect view*

The subject was placed facing the chest X-ray stand with chin in extended position placed over the chin holder, and a cassette of size $14 \times 15$ inch was placed in the cassette stand; the feet of the subject was placed slightly apart to achieve a better stability position. The median sagittal plane was adjusted to right angle to the centre of cassette and centre of stand. The hands of subjects were placed in such a position so that the scapulae would not overlap the respiratory chest area; the dorsal side of each arm was positioned below and behind the hips with elbows in forwarded position. The chest was compressed to the cassette so that breasts thickness was prevented from obscuring the respiratory organs. The PA projection of the chest helped in minimising heart shadow as compared to AP projection. The X-ray beam was focused to the centre of the fourth dorsal vertebra. The field size was restricted to the thorax field, avoiding unwanted exposure to the skull and lower organs.

#### *Image processing*

Computed radiography requires the cassette be removed from the X-ray machine and then placed into a film or

cassette reader. Fujifilm FCR PRIMA was used along with FCR PRIMA CONSOLE to scan an X-ray image. The software IW was used for viewing the image on the computer. This software already has the measurement scales in it, so we were not going to do any calculations by conventional ruler or compass. One of the major benefits of using IW was we did not need to take the hard copy of the radiographs. We can store it in soft copy form, thus making this study more cost-effective.

## Results

A total of 450 PA radiographs were studied with an age range of 5 years to 90 years old in our study. We have collected hundred radiographs in the age group of (0–20) and (71 and above) and 50 each in rest of age groups (21–30, 31–40, 41–50, 51–60, 61–70), with equal number of males and females in each age group, hence 225 radiographs of male and similarly 225 females. The mean age ± standard deviation of the sample was 46.13 ± 23.37; median was 47, and 5 years was the minimum; and 90 was maximum the value. The male and female separate statistical analysis was given in Table 1.

Two hundred forty radiographs have shown the calcification in the lower ribs, whereas in 210 radiographs, calcification of the lower ribs was absent. In 145 male radiographs and 154 female radiographs, lower CC calcification was present. In the first age group (0–20), calcification of the lower rib was not found in any male and female radiographs. In the next age group (21–30), it was present in 18 radiographs: 8 in male and 10 in female radiographs. In 30 radiographs, calcification was found for the age group 31–40. The number of radiographs showing calcification was 50, 50, 50, and 100 for age group 41–50, 51–60, 61–70, and 71 and above respectively (Fig. 4). The earliest radiograph showing calcification was of 22 years old in female and 21 years old in male. Peripheral type of calcification was present in 141 male radiographs. The central type of calcification was obtained in 132 radiographs of females (Table 2). Chi-square test was applied using formula ($\chi^2 = \Sigma(O\text{-}E)^2/E$) (where $O$ = observed frequencies and $E$ = expected frequencies) in MS Excel Windows 11 to find the association between type of calcification and type of sex; statistical probability was calculated for the type of calcification dominant in males and females.

In the case of the degree of calcification of the first rib in age group 0–20, 30 radiographs showed stage 0 of calcification, and 70 radiographs showed stage 1 of calcification. In the next age group of 21–30, 24 radiographs were in stage 1, and 26 radiographs in stage 2. In age

**Table 1** Age distribution with statistical analysis of whole sample and both sexes

| Age group | Average | Count | Std dev | Minimum | Maximum | Median |
|---|---|---|---|---|---|---|
| 0–20 | 16.22 | 100 | 2.88 | 5 | 20 | 17 |
| 21–30 | 25.58 | 50 | 3.03 | 20 | 30 | 25 |
| 31–40 | 35.36 | 50 | 2.76 | 31 | 40 | 35 |
| 41–50 | 44.78 | 50 | 2.54 | 40 | 50 | 45 |
| 51–60 | 55.58 | 50 | 2.35 | 51 | 60 | 55.5 |
| 61–70 | 65.58 | 50 | 2.29 | 62 | 70 | 65 |
| 71 and above | 77.92 | 100 | 4.36 | 71 | 90 | 77 |
| Male | | | | | | |
| 0–20 | 15.72 | 50 | 3.70 | 5 | 20 | 16 |
| 21–30 | 24.08 | 25 | 2.32 | 20 | 28 | 24 |
| 31–40 | 35.24 | 25 | 2.62 | 31 | 40 | 35 |
| 41–50 | 45.4 | 25 | 2.48 | 42 | 50 | 45 |
| 51–60 | 55.16 | 25 | 2.21 | 51 | 60 | 55 |
| 61–70 | 65.52 | 25 | 2.16 | 63 | 70 | 65 |
| 71 and above | 78.14 | 50 | 4.63 | 71 | 90 | 78 |
| Female | | | | | | |
| 0–20 | 16.72 | 50 | 2.32 | 12 | 20 | 17 |
| 21–30 | 27.08 | 25 | 2.99 | 21 | 30 | 26.02 |
| 31–40 | 35.48 | 25 | 2.72 | 31 | 40 | 35.74 |
| 41–50 | 44.16 | 25 | 2.13 | 42 | 48 | 47 |
| 51–60 | 56 | 25 | 2.38 | 51 | 60 | 56 |
| 61–70 | 65.64 | 25 | 2.46 | 62 | 70 | 65 |
| 71 and above | 77.70 | 50 | 4.07 | 71 | 89 | 76.5 |

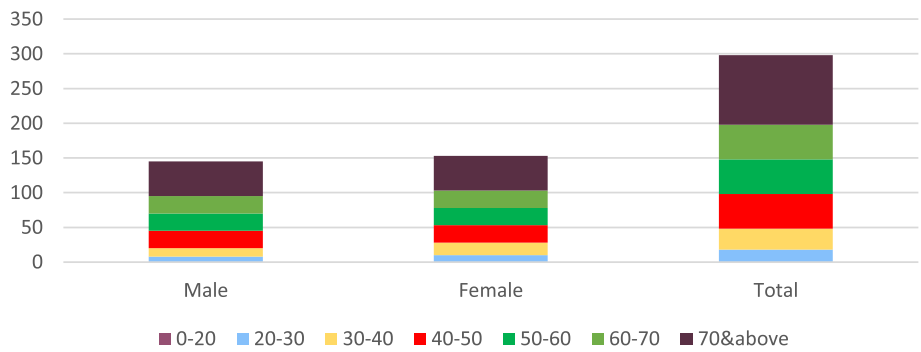



**Fig. 4** Distribution of calcification of lower ribs in different age groups

**Table 2** Distribution of calcification pattern

| Sex | Peripheral | Central | Mixed | Indifferent | Absent | Total |
|---|---|---|---|---|---|---|
| Male | 141 | 0 | 1 | 3 | 80 | 225 |
| Female | 1 | 132 | 9 | 12 | 71 | 225 |
| Total | 142 | 132 | 10 | 15 | 151 | 450 |

**Table 3** Statistical analysis of calcification stages

| Calcification stage | Stage 0 | Stage 1 | Stage 2 | Stage 3 |
|---|---|---|---|---|
| Average | 13.42 | 20.99 | 41.46 | 69.39 |
| Count | 31 | 106 | 129 | 184 |
| Minimum | 5 | 15 | 24 | 45 |
| Maximum | 31 | 42 | 72 | 90 |
| Std dev | 4.08 | 6.17 | 11.49 | 10.80 |
| Median | 14 | 19 | 40 | 73 |

group 71 and above, ninety-six radiographs were in stage 3, and no radiograph was seen in stage 0. The mean age was 13.42 years with standard deviation ±4.08 for stage 0 (Table 3). For stage 1, the mean age ± standard deviation was 20.99 ± 6.17 years; it was 41.46 ± 11.49 years for stage 2 and 69.39 ± 10.80 years for stage 3. The relationship between age of the subjects and calcification of first rib were shown in Fig. 5. The statistical analysis for age estimation was done by using spearman's rho analysis (Fig. 6). These analyses revealed significant positive correlation between age and level of calcification. Value

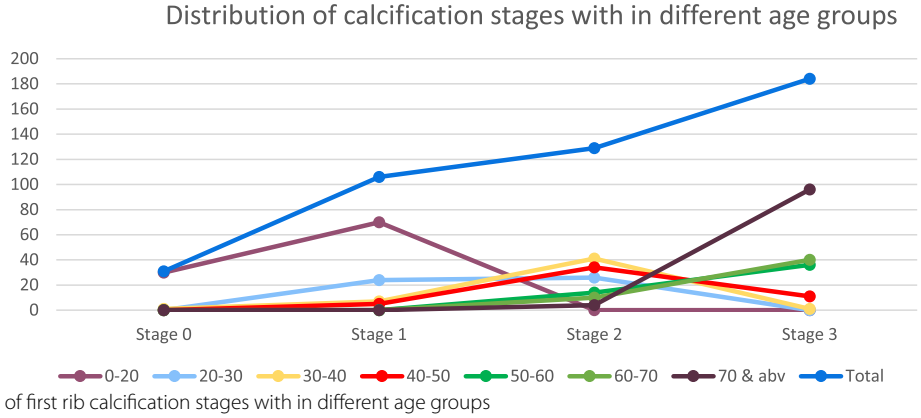



**Fig. 5** Distribution of first rib calcification stages with in different age groups

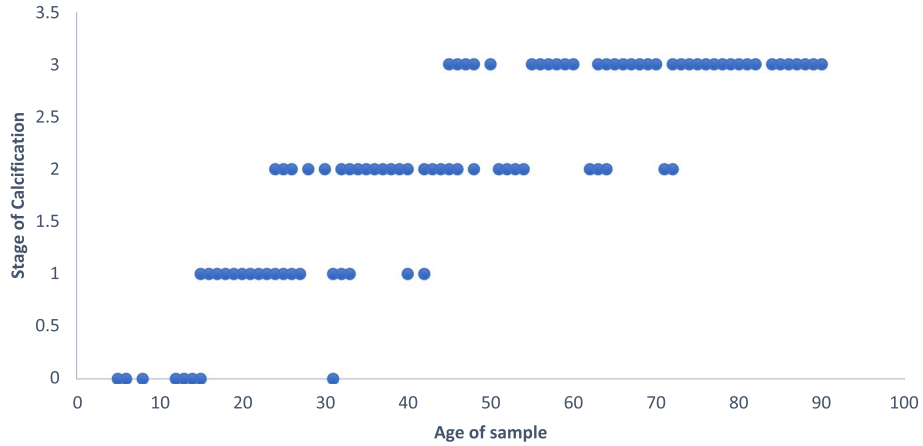



**Fig. 6** Scatter plot showing association between stages of calcification and age

of spearman's rho for sample $r_s = 0.911$, $p < 0.01$ (for male subjects, it was $r_s = 0.921$, $p < 0.01$). For females, it was $r_s = 0.905$, $p < 0.01$).

## Discussion

The present study shows the presence of sexual dimorphism in pattern of calcification in CC. This study consists of radiographs of 5-year-old children to 90 years old. The present study includes sample radiographs of age less than 10 years as compared to earlier studies. Furthermore, this study cooperates the application of software IW which none other authors used or specified in their studies. The number of radiographs showing calcification in this study is 66% which is higher than the Rejartarova study (51.53%) (Rejtarová et al., 2004a, b, c) but less than the Rao and Pai (1988a, b, c) study (77.60%); this may be due to the fact that Navani et al. took the age group of sample more than 10 years, whereas in our study, the minimum age was 5 years. The percentage of calcification also increases with age; in lower CC, it was seen 0.00% in the age group 0–20 and 100% in the age group 61–70. The above study shows peripheral type of calcification in 141 cases of male and in 1 case of females, whereas the central type of calcification was present in 132 females and was absent in males. Elkeles (1966a, b, c) studied 2606 patients (1329 males and 1277 females) with age range 30 years to 80 years and above. The minimum age where calcification was observed was found in a 16-year-old girl; males showed perichondrium type of calcification majority. Shiv Navani et al. (1970) studied 1000 radiographs (10–95 years); they divided the types of calcification as follows: type I (marginal), type II (central), type III, and mixed type. Predictive value for type I was 95%, and for females, it was 93% for type II. The minimum age of calcification in his study was found in a 20-year-old subject, and it was 15 years for Stewart and McCormick (1984a, b, c), but the earliest age showing calcification was found in an 11-year-old Mexican boy in a study conducted by Michelson (1934a, b, c). A study conducted by Rao and Pai (1988a, b, c) on a South Indian population with the age range 1–80 years predicted 92.3% of the type A pattern of calcification in males and 95.5% of type B calcification in females. The probability value for central type of calcification was 100% in case of females in a study conducted by Olga Rejtarova et al., and for males, it was 99.6% for type I calcification. He also studied 18 cases of cadavers along with 1044 patients. Krishan et al. (2016a, b, c) studied 1000 chest radiographs and found earlier calcification in a 15-year-old male and a 17-year-old female. The predictive value for males was 96.6% and 97.6% for females. The estimated predictive value ranges from 93 to 100% in past studies. All these earlier studies showed peripheral type of calcification in males and central type for females.

The statistical probability of peripheral type of calcification in male calculated from the Table 2 was 99.3%, and for females, the probability was 100% which was similar to studies conducted in past; the chi-square test was applied to see the significance between type of CC and sex and the results; the value of $\chi^2$ was 280.58 $df = 3$, and $p$ value $< 0.01$ shows there was an association between the type of calcification and sex, and this association was statically significant. Using such a simple and cheap method, our study shows the presence of dimorphism in the costal cartilage.

The regions in the human body undergo extensive changes throughout human lifespan; the thoracic region is among those parts. The first rib undergoes calcification prior to other ribs (Ikeda, 2017a, b, c). Different authors in the past used different methods based on radiography, osteology, and measurement of the skeleton for estimation of age. The earlier authors in the past suggested that calcification of the first CC is a real process of ossification. According to them, the main cause of calcification or ossification in the first rib is due to the generation of respiratory stress, whereas for lower ribs, expansion of the chest is the main cause. The estimation of age was also possible with the help of calcification pattern and degree of calcification in lower cartilages but better understood and visualised by first rib calcification. From the results of our study, till the age of 30, there was no radiograph showing the stage 3 of calcification; in a previous study conducted by Michelson, when a subject has calcification in stage 0, his chronological age will be less than 25 years and less than 20 years in a study conducted by Garamendi et al. (2011a, b, c); in our study, stage 0 was present between the age group 5 and 30 years; for stage 1, it was between 15 and 44; stage 2 was observed in the 26–72 age group, and for stage 3, it was seen in 40–90 years. With increasing age, the calcification stage also increases, and in the age group of 71 and above, there was no radiograph showing stage 0. The mean age of calcification for stage 0 was 18.03, 28.09, 45.74, and 55.56 for stages 1, 2, and 3 respectively in the Garamendi study. In our study, the mean age obtained for stage 0, 1, 2, and 3 were 13.42, 20.99, 41.46, and 69.39. The median for stage 0 was 14 in our study, whereas for the Garamendi et al. study, it was 17.64 and 5 in a study conducted on the Turkish population (Karaman et al., 2012a, b, c). This difference is due to the difference in sample age in different studies, and the Turkish study had more children in their study sample as compared to our study. The value of spearman rho obtained was close to one that shows the study was significant in terms of age estimation. One of the limitations of our study was its retrospective nature and sample size. More studies in the future on different populations are needed to validate or reject these conclusions. For age group 0–20, different methods like estimation with the help of wrist radiograph gives more promising results as there are tremendous changes in bone fusion during the time of growing, but for later age groups like above 50 years, the changes in skeleton are not so prominent for evaluation; in that case, calcification stages of costal cartilage will be beneficial among subjects ranging from 30 years to 70 years and above.

Premature CC calcification may be associated with certain disorders like malignancy, chronic renal failure, Graves' disease, and autoimmune disorders (Ontell et al., 1997a, b, c). In cases when there are pathological conditions or places where the subject may be exposed to unusual respiratory stress, the results should be taken with special precautions, and a different study is required. Further studies on other populations should be conducted for age and sex estimation and for comparing the results of our study before its application in medicolegal or forensic context.

## Conclusions

The assessment of type of costal cartilage pattern is useful in determining the sex when the thorax region is only present. Calcification of the superior and inferior margins of the costal cartilages is characteristic of the peripheral type, and this pattern tends to occur in males. Calcification of the central parts of the costal cartilages is found mainly in female individuals. The mixed pattern of calcification is a combination of the peripheral pattern and the central pattern and thus cannot determine the sex of an individual. This study is an attempt to study the influence of costal cartilage calcification on age and sex. The degree of calcification is useful in estimating age groups and becomes more determined with advancing age. Although the role of coastal cartilage in sex estimation had been studied, there are limitations from population to population. Majorities of the studies have been done in small sample sizes. A large study with a larger population will be needed. While the study has some limitations, the study does reveal that data obtained from the radiographs will make useful indicators for age of an individual. Prediction of sex by using radiological method gives the advantages of simplicity, inexpensiveness, speed, and high accuracy. The above explained method for the age and sex estimation will play useful role in screening test and in forensic cases where the thoracic part is only present. Hence, integration of such radiological method with the combination of the software's will enhance the estimation of sex and age.

#### Abbreviations

CT: Computed tomography; PA: Posterior anterior; IW: Image works; CC: Costal cartilage.

#### Acknowledgements

Not applicable

#### Authors' contributions

SP collected the data from the hospital. TB and SP analysed and interpreted the patient data regarding age and sex. TB participated in its design and coordination and helped to draft the manuscript. SP contributed in writing the manuscript under the guidance of TB. All authors read and approved the final manuscript.

#### Funding

Not applicable

**Availability of data and materials**
The datasets used or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate**
The Institutional Ethical Committee (IEC) of Dr. Radhakrishnan Government Medical College Hamirpur, Himachal Pradesh, India, provided permission to perform this study (No. HFW-H-Dr. RKGMC/Ethics/2022/02, Registration No. ECR/1461/Inst/HP/2020). Since this study is retrospective, informed consent form was not used.

**Consent for publication**
Not applicable

**Competing interests**
The authors declare that they have no competing interests.

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Received: 6 May 2022 Accepted: 12 September 2022
Published online: 29 September 2022

**References**

Barchilon V, Hershkovitz I, Rothschild BM, Wish-Baratz S, Latimer B, Jellema LM, Hallel T, Arensburg B (1996a) Factors affecting the rate and pattern of the first costal cartilage ossification. Am J Forensic Med Pathol 17:239
Barchilon V, Hershkovitz I, Rothschild BM, Wish-Baratz S, Latimer B, Jellema LM, Hallel T, Arensburg B (1996b) Factors affecting the rate and pattern of the first costal cartilage ossification. Am J Forensic Med Pathol 17:239
Barchilon V, Hershkovitz I, Rothschild BM, Wish-Baratz S, Latimer B, Jellema LM, Hallel T, Arensburg B (1996c) Factors affecting the rate and pattern of the first costal cartilage ossification. Am J Forensic Med Pathol 17:239
de Boer HH, Obertová Z, Cunha E, Adalian P, Baccino E, Fracasso T, Kranioti E, Lefévre P, Lynnerup N, Petaros A, Ross A, Steyn M, Cattaneo C (2020a) Strengthening the role of forensic anthropology in personal identification: position statement by the Board of the Forensic Anthropology Society of Europe (FASE). Forensic Sci Int. https://doi.org/10.1016/j.forsciint.2020.110456
de Boer HH, Obertová Z, Cunha E, Adalian P, Baccino E, Fracasso T, Kranioti E, Lefévre P, Lynnerup N, Petaros A, Ross A, Steyn M, Cattaneo C (2020b) Strengthening the role of forensic anthropology in personal identification: position statement by the Board of the Forensic Anthropology Society of Europe (FASE). Forensic Sci Int. https://doi.org/10.1016/j.forsciint.2020.110456
de Boer HH, Obertová Z, Cunha E, Adalian P, Baccino E, Fracasso T, Kranioti E, Lefévre P, Lynnerup N, Petaros A, Ross A, Steyn M, Cattaneo C (2020c) Strengthening the role of forensic anthropology in personal identification: position statement by the Board of the Forensic Anthropology Society of Europe (FASE). Forensic Sci Int 315:110456. https://doi.org/10.1016/j.forsciint.2020.110456
Dedouit F, Bindel S, Gainza D, Blanc A, Joffre F, Rougé D, Telmon N (2008a) Application of the Iscan method to two- and three-dimensional imaging of the sternal end of the right fourth rib. J Forensic Sci 53(2):288. https://doi.org/10.1111/j.1556-4029.2007.00642.x
Dedouit F, Bindel S, Gainza D, Blanc A, Joffre F, Rougé D, Telmon N (2008b) Application of the Iscan method to two- and three-dimensional imaging of the sternal end of the right fourth rib. J Forensic Sci 2. https://doi.org/10.1111/j.1556-4029.2007.00642.x
Dedouit, F, Bindel, S, Gainza, D, Blanc, A, Joffre, F, Rougé, D and Telmon, N (2008c) Application of the Iscan method to two- and three-dimensional imaging of the sternal end of the right fourth rib. J Forensic Sci 2. https://doi.org/https://doi.org/10.1111/j.1556-4029.2007.00642.x
Elkeles A (1966a) Sex differences in the calcification of the costal cartilages. J Am Geriatr Soc 14:456
Elkeles A (1966b) Sex differences in the calcification of the costal cartilages. J Am Geriatr Soc 14(5):456–462
Elkeles A (1966c) Sex differences in the calcification of the costal cartilages. J Am Geriatr Soc 14:456
Fanton L, Gustin M-P, Paultre U, Schrag B, Malicier D (2010a) Critical study of observation of the sternal end of the right 4th rib. J Forensic Sci 2. https://doi.org/10.1111/j.1556-4029.2009.01279.x
Fanton L, Gustin M-P, Paultre U, Schrag B, Malicier D (2010b) Critical study of observation of the sternal end of the right 4th Rib. J Forensic Sci 2. https://doi.org/10.1111/j.1556-4029.2009.01279.x
Fanton L, Gustin M-P, Paultre U, Schrag B, Malicier D (2010c) Critical study of observation of the sternal end of the right 4th rib. J Forensic Sci 2. https://doi.org/10.1111/j.1556-4029.2009.01279.x
Fischer E (1955a) Verkalkungsformen der Rippenknorpel. RöFo - Fortschritte auf dem Gebiet der Röntgenstrahlen und der Bildgeb Verfahren 04. https://doi.org/10.1055/s-0029-1212570
Fischer E (1955b) Verkalkungsformen der Rippenknorpel. RöFo - Fortschritte auf dem Gebiet der Röntgenstrahlen und der Bildgeb Verfahren 04. https://doi.org/10.1055/s-0029-1212570
Fischer, E (1955c) Verkalkungsformen der Rippenknorpel. RöFo - Fortschritte auf dem Gebiet der Röntgenstrahlen und der Bildgeb Verfahren 04. https://doi.org/https://doi.org/10.1055/s-0029-1212570
Garamendi PM, Landa MI, Botella MC, Alemán I (2011a) Forensic age estimation on digital X-ray images: medial epiphyses of the clavicle and first rib ossification in relation to chronological age. J Forensic Sci 56(SUPPL. 1):3–12. https://doi.org/10.1111/j.1556-4029.2010.01626.x
Garamendi PM, Landa MI, Botella MC, Alemán I (2011b) Forensic age estimation on digital X-ray Images: medial epiphyses of the clavicle and first rib ossification in relation to chronological age. J Forensic Sci 56(SUPPL. 1):3–12. https://doi.org/10.1111/j.1556-4029.2010.01626.x
Garamendi PM, Landa MI, Botella MC, Alemán I (2011c) Forensic age estimation on digital X-ray images: medial epiphyses of the clavicle and first rib ossification in relation to chronological age. J Forensic Sci 56(SUPPL. 1):3–12. https://doi.org/10.1111/j.1556-4029.2010.01626.x
Ikeda T (2017a) Estimating age at death based on costal cartilage calcification. Tohoku J Exp Med 4. https://doi.org/10.1620/tjem.243.237
Ikeda T (2017b) Estimating age at death based on costal cartilage calcification. Tohoku J Exp Med 4. https://doi.org/10.1620/tjem.243.237
Ikeda T (2017c) Estimating age at death based on costal cartilage calcification. Tohoku J Exp Med 4. https://doi.org/10.1620/tjem.243.237
Inoi T (1997a) Estimation of sex and age by calcification pattern of costal cartilage in Japanese. Nihon Hoigaku Zasshi= Japanese. J Leg Med 2
Inoi T (1997b) Estimation of sex and age by calcification pattern of costal cartilage in Japanese. Nihon Hoigaku Zasshi= Japanese J Leg Med 51:89
Inoi T (1997c) Estimation of sex and age by calcification pattern of costal cartilage in Japanese. Nihon Hoigaku Zasshi= Japanese J Leg Med 51:89
Kampen WU, Ciaassen H, Kirsch T (1995a) Mineralization and osteogenesis in the human first rib cartilage. Ann Anat - Anat Anzeiger 2. https://doi.org/10.1016/S0940-9602(11)80069-5
Kampen WU, Ciaassen H, Kirsch T (1995b) Mineralization and osteogenesis in the human first rib cartilage. Ann Anat - Anat Anzeiger 2. https://doi.org/10.1016/S0940-9602(11)80069-5
Kampen WU, Ciaassen H, Kirsch T (1995c) Mineralization and osteogenesis in the human first rib cartilage. Ann Anat - Anat Anzeiger 2. https://doi.org/10.1016/S0940-9602(11)80069-5
Karaman B, Battal B, Bozkurt Y, Kantarci MN, Gümüş S, Özcan ME, Açikel CH (2012a) Age determination in turkish people based on the calcification degree of the first costal cartilage. Turkiye Klin J Med Sci 32(5):1361–1367. https://doi.org/10.5336/medsci.2011-27529
Karaman B, Battal B, Bozkurt Y, Kantarci MN, Gümüş S, Özcan ME, Açikel CH (2012b) Age determination in turkish people based on the calcification degree of the first costal cartilage. Turkiye Klin J Med Sci 32(5):1361–1367. https://doi.org/10.5336/medsci.2011-27529
Karaman B, Battal B, Bozkurt Y, Kantarci MN, Gümüş S, Özcan ME, Açikel CH (2012c) Age determination in turkish people based on the calcification degree of the first costal cartilage. Turkiye Klin J Med Sci 32(5):1361–1367. https://doi.org/10.5336/medsci.2011-27529
Khatri K, Khanna J, Chauhan R, Bhargava SK (2009a) Determination of sex by calcification pattern of costal cartilages in Indian population. J Forensic Med Toxicol 26(2):18–22

Khatri K, Khanna J, Chauhan R, Bhargava SK (2009b) Determination of sex by calcification pattern of costal cartilages in Indian population. J Forensic Med Toxicol 26(2):18–22
Khatri K, Khanna J, Chauhan R, Bhargava SK (2009c) Determination of sex by calcification pattern of costal cartilages in Indian population. J Forensic Med Toxicol 26(2):18–22
King JB (1939a) Calcification of the costal cartilages. Br J Radiol 133. https://doi.org/10.1259/0007-1285-12-133-2
King JB (1939b) Calcification of the costal cartilages. Br J Radiol 133. https://doi.org/10.1259/0007-1285-12-133-2
King JB (1939c) Calcification of the costal cartilages. Br J Radiol 133. https://doi.org/10.1259/0007-1285-12-133-2
Klales AR (2020a) Practitioner preferences for sex estimation from human skeletal remains. – Sex Estimation of the Human Skeleton. Elsevier, pp 11–23. https://doi.org/10.1016/B978-0-12-815767-1.00002-X
Klales, AR (2020b) Practitioner preferences for sex estimation from human skeletal remains. – Sex Estimation of the Human Skeleton. pp. 11–23. https://doi.org/10.1016/B978-0-12-815767-1.00002-X
Klales AR (2020c) Practitioner preferences for sex estimation from human skeletal remains. – Sex Estimation of the Human Skeleton. Elsevier:11–23. https://doi.org/10.1016/B978-0-12-815767-1.00002-X
Krishan K, Chatterjee PM, Kanchan T, Kaur S, Baryah N, Singh RK (2016a) A review of sex estimation techniques during examination of skeletal remains in forensic anthropology casework. Forensic Sci Int. https://doi.org/10.1016/j.forsciint.2016.02.007
Krishan K, Chatterjee PM, Kanchan T, Kaur S, Baryah N, Singh RK (2016b) A review of sex estimation techniques during examination of skeletal remains in forensic anthropology casework. Forensic Sci Int. https://doi.org/10.1016/j.forsciint.2016.02.007
Krishan K, Chatterjee PM, Kanchan T, Kaur S, Baryah N, Singh RK (2016c) A review of sex estimation techniques during examination of skeletal remains in forensic anthropology casework. Forensic Sci Int. https://doi.org/10.1016/j.forsciint.2016.02.007
McCormick WF, Stewart JH, Langford LA (1985a) Sex determination from chest plate roentgenograms. Am J Phys Anthropol 68(2):173. https://doi.org/10.1002/ajpa.1330680205
McCormick WF, Stewart JH, Langford LA (1985b) Sex determination from chest plate roentgenograms. Am J Phys Anthropol 68:173. https://doi.org/10.1002/ajpa.1330680205
McCormick WF, Stewart JH, Langford LA (1985c) Sex determination from chest plate roentgenograms. Am J Phys Anthropol 2. https://doi.org/10.1002/ajpa.1330680205
Michelson N (1934a) The calcification of the costal cartilage among whites and negroes. Hum Biol 6(3):543–547
Michelson N (1934b) The calcification of the first costal cartilage among whites and negroes. Hum Biol 6:543–7
Michelson N (1934c) The calcification of the first costal cartilage among whites and negroes. Hum Biol 6:543
Middleham HP, Boyd LE, McDonald SW (2015a) Sex determination from calcification of costal cartilages in a Scottish sample. Clin Anat 28(7):888–895. https://doi.org/10.1002/ca.22491
Middleham HP, Boyd LE, McDonald SW (2015b) Sex determination from calcification of costal cartilages in a Scottish sample. Clin Anat 28(7):888–895. https://doi.org/10.1002/ca.22491
Middleham, HP, Boyd, LE and McDonald, SW (2015c) Sex determination from calcification of costal cartilages in a Scottish sample. Clin Anat 28(7):888–895. https://doi.org/10.1002/ca.22491
Navani SS, Sha JR, Levy PS (1970) Determination of sex by costal cartilage calcification. Am J Roentgenol 108(4):771–774
Ontell FK, Moore EH, Shepard JA, Shelton DK (1997a) The costal cartilages in health and disease, p 3. https://doi.org/10.1148/radiographics.17.3.9153697
Ontell FK, Moore EH, Shepard JA, Shelton DK (1997b) The costal cartilages in health and disease. Radiographics 17:571. https://doi.org/10.1148/radiographics.17.3.9153697
Ontell FK, Moore EH, Shepard JA, Shelton DK (1997c) The costal cartilages in health and disease, p 3. https://doi.org/10.1148/radiographics.17.3.9153697
Patyal S and Tejasvi, B (2021) Artificial intelligence with radio-diagnostic modalities in forensic science-a systematic review. CEUR Workshop Proc
Rao NG, Pai LM (1988a) Costal cartilage calcification pattern - a clue for establishing sex identity. Forensic Sci Int 38(3–4):193–202. https://doi.org/10.1016/0379-0738(88)90166-1
Rao NG, Pai LM (1988b) Costal cartilage calcification pattern - a clue for establishing sex identity. Forensic Sci Int 38(3–4):193–202. https://doi.org/10.1016/0379-0738(88)90166-1
Rao NG, Pai LM (1988c) Costal cartilage calcification pattern - a clue for establishing sex identity. Forensic Sci Int 38(3–4):193–202. https://doi.org/10.1016/0379-0738(88)90166-1
Rejtarová O, Slízová D, Smoranc P, Rejtar P, Bukac J (2004a) Costal cartilages--a clue for determination of sex. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub 148(2):241–243. https://doi.org/10.5507/bp.2004.050
Rejtarová O, Slízová D, Smoranc P, Rejtar P, Bukac J (2004b) Costal cartilages--a clue for determination of sex. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub 148(2):241–243. https://doi.org/10.5507/bp.2004.050
Rejtarová O, Slízová D, Smoranc P, Rejtar P, Bukac J (2004c) Costal cartilages--a clue for determination of sex. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub 148(2):241–243. https://doi.org/10.5507/bp.2004.050
Semine AA, Damon A (1975a) Costochondral ossification and aging in five populations. Hum Biol 47:101–116
Semine AA, Damon A (1975b) Costochondral ossification and aging in five populations. Hum Biol:101
Semine AA, Damon A (1975c) Costochondral ossification and aging in five populations. Hum Biol
Patyal Shama and Tejasvi, B (2021a) Artificial intelligence with radio-diagnostic modalities in forensic science-a systematic review. CEUR Workshop Proc
Patyal Shama and Tejasvi, B (2021b) Artificial intelligence with radio-diagnostic modalities in forensic science-a systematic review. CEUR Workshop Proc
Stewart JH, McCormick WF (1984a) A sex- and age-limited ossification pattern in human costal cartilages. Am J Clin Pathol 81(6):765–769. https://doi.org/10.1093/ajcp/81.6.765
Stewart JH, McCormick WF (1984b) A sex- and age-limited ossification pattern in human costal cartilages. Am J Clin Pathol 81(6):765–769. https://doi.org/10.1093/ajcp/81.6.765
Stewart JH, McCormick WF (1984c) A sex- and age-limited ossification pattern in human costal cartilages. Am J Clin Pathol 81(6):765–769. https://doi.org/10.1093/ajcp/81.6.765
Vastine JH 2nd, Vastine MF, Arango O (1948a) Myositis ossificans progressiva in nomozygotic twins. Am J Roentgenol Radium Ther 59, 204
Vastine JH 2nd, Vastine MF, Arango O (1948b) Myositis ossificans progressiva in nomozygotic twins. Am J Roentgenol Radium Ther 59:204
Vastine JH 2nd, Vastine MF, Arango O (1948c) Myositis ossificans progressiva in nomozygotic twins. Am J Roentgenol Radium Ther 59:204
Yaşar İşcan M, Loth SR, Wright RK (1984a) Age estimation from the rib by phase analysis: white males. J Forensic Sci 29:1094. https://doi.org/10.1520/JFS11776J
Yaşar İşcan M, Loth SR, Wright RK (1984b) Age estimation from the rib by phase analysis: white males. J Forensic Sci 29(4):1094. https://doi.org/10.1520/JFS11776J
Yaşar İşcan M, Loth SR, Wright RK (1984c) Age estimation from the rib by phase analysis: white males. J Forensic Sci 65(2):147–156. https://doi.org/10.1520/JFS11776J

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