IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 16, Issue 3 Ver. VII (March. 2017), PP 115-123
www.iosrjournals.org

A Study of Calcification of Costal Cartilages (1st To 7th) In Different Age Groups and Its Effect on Chest Expansion in Both Male and Female

Dr. Koushik Ray[1], Dr. Jayati Bardhan[2], Dr. Kashi Nath Sarkar[3]
[1](Junior Resident III, Department of Anatomy, Bankura sammilani medical college, Bankura, India)
[2](Associate Professor, Department of Radio diagnosis, Bankura sammilani medical college, Bankura, India)
[3](Junior Resident III, Department of Radio diagnosis, Bankura sammilani medical college, Bankura, India)

Background: *Costal cartilage calcification progresses with age and shows differences in sexual preponderance. Studies have been done on these parameters. But, few studies have been done encompassing both age, sex and effect of calcification on chest expansion.*
Aims: *1. To study the incidence of costal cartilage calcification in different age groups in both sexes.*
2. To evaluate the effect of costal cartilage calcification on chest expansion in the same population.
Materials and methods: *Data was analyzed using Chi-Square test with yate's correction in IBM SSPS statistics 24 and MS excel.*
Results: *In our study, distribution of costal cartilage calcification in different age groups were 3 in the age group of 30-40 years (9%), 5 in 41-50 years (15%), 9 in 51-60 years (26%) &17 cases in 61 to 70 years (50%). The mean chest expansion was 2.331 with SD 0.827 with range of 1cm-4cm & Standard Error of Mean(SEM) 0.0832. Chi squared value was 19.042 with 1 degrees of freedom. Two tailed P value was <0.0001.*
Conclusions: *In both male & female, costal cartilage calcification followed similar distributions with males (56%) being affected more than females (44%). Apart from the age group of 41-50 years, males were affected more than females in all age groups. In both genders, incidence of costal cartilage calcification was low in the age group of 30-40 years & gradually increased with age. Below the chest expansion range of 2.5 cm, the incidence of costal cartilage calcification increases significantly indicating its effect on chest wall rigidity. Since costal cartilage calcification significantly reduces chest wall flexibility with increasing age and increases workload of respiration, it is an important factor to be kept in mind while treating and evaluating the chest X-ray of aged patients complaining dyspnea on exertion.*
Keywords *costal cartilage calcification, chest expansion*

I. Introduction

The skeleton of the thoracic wall consists of twelve thoracic vertebrae, twelve pairs of ribs with their costal cartilages and the sternum. These twelve pairs of ribs articulate with the vertebral column posteriorly and is continued as costal cartilages anteriorly to join the sternum. The first chondrosternal joint is a primary cartilaginous joint which is known to ossify as early as 15 years of age [1]. It provides stability to the sterno-clavicular joint during movement of the shoulder girdle. Second to seventh chondrosternal joints are synovial type of joints which provides mobility to the chest wall. The number of ribs may be increased by cervical or lumbar ribs or reduced by the absence of the twelfth pair. The first seven pairs are connected to the sternum by costal cartilages, and are referred to as the true ribs. The remaining five are the false ribs: the cartilages of the eighth to tenth usually join the suprajacent costal cartilage, whereas the eleventh and twelfth ribs, which are free at their anterior ends, are termed the 'floating' ribs. Ribs increase in length from the first to seventh, and thereafter diminish to the twelfth. A typical rib has a shaft with anterior and posterior ends. The anterior, costal, end has a small concave depression for the lateral end of its cartilage. The shaft has an external convexity and is grooved internally near its lower border, which is sharp, whereas its upper border is rounded. The posterior, vertebral end has a head, neck and tubercle. The head presents two facets, separated by a transverse crest. The lower and larger facet articulates with the body of the corresponding vertebra. The costal cartilages are flat bars of hyaline cartilage that extend from the anterior ends of the ribs and contribute greatly to thoracic flexibility and elasticity. The hyaline costal cartilage is a flexible linkage connecting the bony ribs to the sternum. It is known to calcify in humans. Chondrocytes secrete Alkaline phosphatase which hydrolyses alkaline phosphates to free phosphate ions. The latter combines with soluble calcium of the tissue fluid to precipitate in the matrix of cartilage tissue as calcium phosphate. This process is known as calcification. The costal cartilages are visible on radiographs only when there is calcification within them. Costal cartilages are prone to calcification after adolescence[5]. Prevalence of costal cartilage calcification increases with age from about 6% in 3rd decade of life to 45% in 9th decade of life [6]. Radiographic examination of costal cartilages is useful and convenient for

estimating age and sex of an individual. The individual variation in the appearance of first costal cartilage calcification can be used for the identification of individuals by chest radiographs [7]. Previous studies have attempted to correlate costal cartilage calcification with many pathological states, e.g. arteriosclerosis, nutritional state, metabolic or endocrine changes and genetic variation [5,8,9]. Differences between males and females in costal cartilage calcification were first described in 1955 in a study which emphasised endocrine influences on the calcification of the hyaline cartilages [10]. Mineralisation in the first rib cartilage are physiological, age related changes, which cannot be regarded as degenerative processes. Ossifications appear sooner and more massively in the first than in other ribs. They are often complete, especially in men [11]. Costochondral calcification (CC) is uncommon in people under 30 years of age and follows gender related pattern [12]. Although age estimation is used for identification purposes in the developed countries, in some countries, it is carried out to determine the real age of a person with an already known identity because of inaccurate birth records especially in rural regions. Bone and cartilage are important tissues in determining the age of death in forensic medicine. Bones, even fragments, can be used for age prediction microscopically and provide an approximate age-at death[15]. One of the other structures studied for this reason is costochondral junction [19-21]. Vastine *et al.* have shown striking similarities in the costal cartilage calcification pattern of a pair of homozygotic twins and have concluded that costal cartilage calcification is determined primarily by genetic influences [5]. Our study will be encompassing the distribution of costal cartilage calcification in different age groups in both male and female and its effect on chest expansion. The reduction of lung flexibility in combination with respiratory muscle weakness and chest wall stiffening due to ageing diminishes pulmonary function. The weakening of the respiratory muscles and the stiffening of the chest wall due to calcification of costal cartilages and sternocostal joints are common age-related changes seen in 26% of population, which may result in a substantial decrease in volume displacement of the lungs during respiration. Thoracic cage calcification usually initiates from costochondral junctions and extends toward the sternocostal junctions [12,30]. Thoracic expansion measurement is commonly used as an outcome parameter during in-hospital treatment or in the outpatient clinic. It is simple tool and takes less time. Thoracic expansion that is difference between inspiration and expiration in adult is 3 to 7.5 cm.

II. Materials And Methods

A Single institution based cross sectional study with purposive sampling was conducted in department of Radiodiagnosis, among 100 subjects (50 Male and 50 female) in the age group of 30 to 70 years attending outpatient department of Bankura Sammilani Medical College, as attendant of patients and were not suffering from any known lung disease, over a study period of 1year and 6 months approx. from June 2015 to December 2016. Study was approved by institutional ethics committee and consent were obtained from all study participants. Study tools included X-ray machine (500 MA with IITV and digital radiography), Measuring tape and Centimeter scale with gradation in millimeter. A detailed history with review of previous reports was taken from all the subjects in pertinence to inclusion and exclusion criteria as briefed below.

Inclusion criteria:

a) Healthy subjects, not suffering from any known lung disease.
b) Subjects within age group of 30-70 years.

Exclusion criteria;

a) Subjects with known lung disease.
b) Seriously ill persons.
c) Smokers.
d) Past history of chest injury.
e) Persons not willing to participate in the study.

Those who fitted in inclusion criteria underwent chest X-ray posterior-anterior view and their chest expansion was measured with a measuring tape in centimeter at the level of xiphoid process. The measuring tape was encircled firmly and horizontally around the chest wall at the level of xiphoid. Xiphoid notch is the bony, inverted "V" at the base of the sternum. The subject were instructed to keep their hands on their heads and to hold breath once in the end of full inspiration & again at the end of full expiration. Two chest expansion measurements were taken for each subject. One chest circumference measure was taken at full inhalation and a second one at full exhalation. Subtracting the values yield the maximum chest expansion of an individual

III. Figures And Tables

Table 1: Distribution Of Calcification Of Costal Cartilages In Different Age Groups(N=100)

Age groups(yrs)	Calcification absent	calcification present	Total
30-40	12	03	15
41-50	21	05	26
51-60	18	09	27
61-70	15	17	32
TOTAL	63	37	100

Table2: Distribution Of Costal Cartilage Calcification In Males In Different Age Groups

Age(M)	Calcification Absent	Calcification Present	Total
30-40	4	2	6
41-50	7	2	9
51-60	10	05	15
61-70	10	10	20
Total	31	19	50

In males, the incidence of calcifications increases with age, mostly affecting the age group of 61-70 years

Table 3: Distribution Of Costal Cartilage Calcification In Females In Different Age Groups

Age(F)	Calcification Absent	Calcification Present	Total
30-40	08	01	09
41-50	14	03	17
51-60	08	04	12
61-70	05	07	12
Total	35	15	50

The incidence of costal cartilage calcification increases in females with increasing age similar to males mostly affecting the 61-70 years of age group.

Table 4 distribution of costal cartilage calcification in both genders (n = 100)

Sex	Calcification Absent	Calcification Present	Total
Male	31	19	50
Female	35	15	50
Total	66	34	100

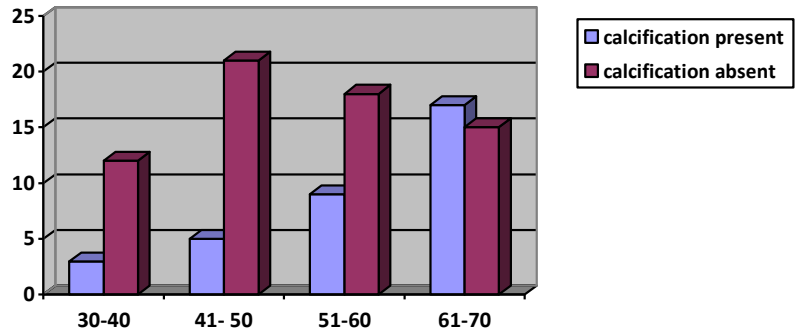


Figure 1: Distribution Of Calcification Of Costal Cartilages In Different Age Groups (N=100)

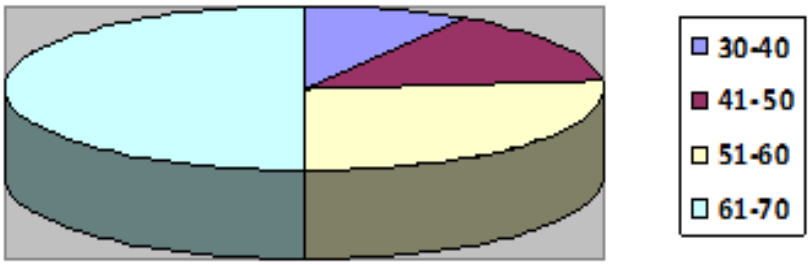


Figure 2: Costal cartilage calcification is more in the 61 -70 years of age group. **(**61-70 approx. 50%)

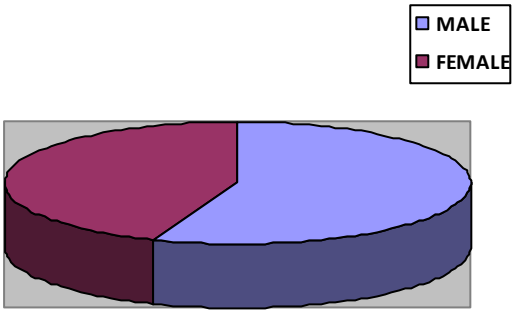


Figure 3: Distribution Of Costal Cartilage Calcification In Both Genders
(N 100) Overall incidence of costal cartilage calcification is more in males.

Table 5: Comparison Of Incidence Of Costal Cartilage Calcification In Two Genders In Deifferent Age Groups (N=34)

Age	Calcification Present(Male)	Calcification Present(Female)	Total
30-40	02	01	03
41-50	02	03	05
51-60	05	04	09
61-70	10	07	17
Total	19	15	34

Apart from the age group of 41 50 years, males are affected more than females.

Table 6: Distribution Of Chest Expansion In Different Age Groups (N=100) Chest Expansion Ranges

Age Groups	1-1.5	1.6-2.0	2.1-2.5	2.6-3.0	3.1-3.5	3.6-04	TOTAL
30-40	00	02	4	4	0	5	15
41-50	0	4	2	14	4	2	26
51-60	4	6	13	4	0	0	27
61-70	16	13	03	0	0	0	32
TOTAL	20	25	22	22	4	7	100

Maximum range of chest expansion is seen in age group of 30-40 years. Chest expansion gradually decreases as age advances. The minimum chest expansion of 1-1.5 cm is seen in 61-70 years of age group. In case of male Minimum chest expansion is seen in 61 -70 years of age group in males. In case of female with exception of the range 3.1-3.5 cm of expansion, where no case was found, the pattern is similar to males, decreasing chest expansion with increasing age

Table 7: Distribution Of Calcification With Chest Expansion (N=100)

Expansion(Cm)	Calcification Absent	Calcification Present	Total
1-1.5	00	20	20
1.6-2.0	14	11	25
2.1-2.5	20	02	22
2.6-3.0	22	02	22
3.1-3.5	04	00	04
3.6-4.0	06	01	07
Total	66	34	100

The incidence of calcification is more in the minimum range of chest expansion (1cm-1.5cm).

Table 8: Distribution Of Calcification With Chest Expansion In Males (N=50)

Expansion(Cm)	Calcification Absent	Calcification Present	Total
1-1.5	00	10	10
1.6-2.0	08	06	14
2.1-2.5	09	02	11
2.6-3.0	06	00	06
3.1-3.5	4	0	4
3.6-4.0	4	1	5
Total	31	19	50

In males, with increasing incidence of costal cartilage calcification, chest expansion decreases significantly

Table 9: Distribution Of Calcification With Chest Expansion In Females (N=50)

Expansion(Cm)	Calcification Absent	Calcification Present	Total
1-1.5	00	10	10
1.6-2.0	06	05	11
2.1-2.5	11	00	11
2.6-3.0	16	00	16
3.1-3.5	0	0	0
3.6-4.0	02	00	02
Total	35	15	50

In case of females also, increasing incidence of costal cartilage calcification, chest expansion decreases significantly

Table 10: Mean & Standard Deviation Of Chest Expansion

	Mean	Median	Standard deviation(SD)	Standard error of mean(se)	Total no. of cases(n)	Range of expansion
Total study population	2.331	2.5	0.827	0.0832	100	1-4 cm
Males	2.34	2.4	0.898	0.128	50	1-4 cm
Females	2.322	2.5	0.759	0.108	50	1-4 cm

Table13 :Correlation Between Costal Cartilage Calcification And Chest Expansion (Chi-Squared Test With Yate's Correction)

	Costal calcification present	Costal calcification absent	Total
Chest expansion below 2.5 cm	17	15	32
Chest expansion above 2.5 cm	18	00	18
Total	35	15	50

Chi squared equals 19.042 with 1 degrees of freedom
Two tailed P value is <0.0001. by conventional criteria , it is statistically significant.

Table 14: Comparative Analysis Of Chest Expansion In Different Studies

Authors name	Mean with SD
Moll & Wright	2.81±0.73
Kritica Baruah [35]	0.62±0.35
Kim CB [36]	3.2±0.7
Present study	2.331±0.827

Fig 1: Measurement of chest expansion being taken

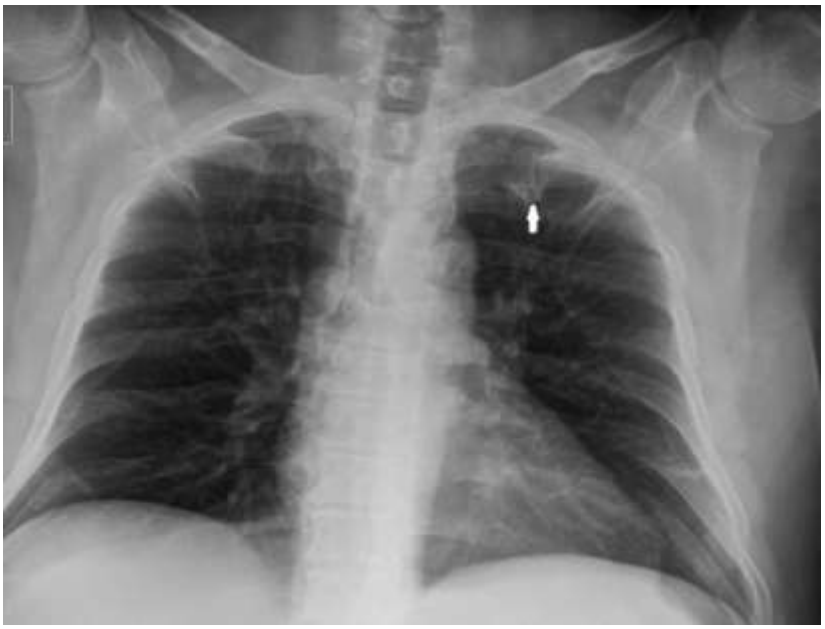
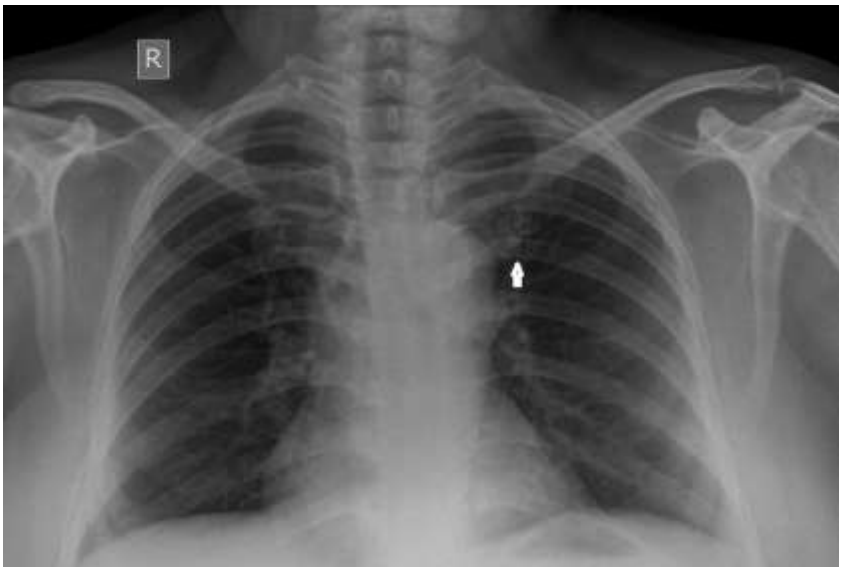
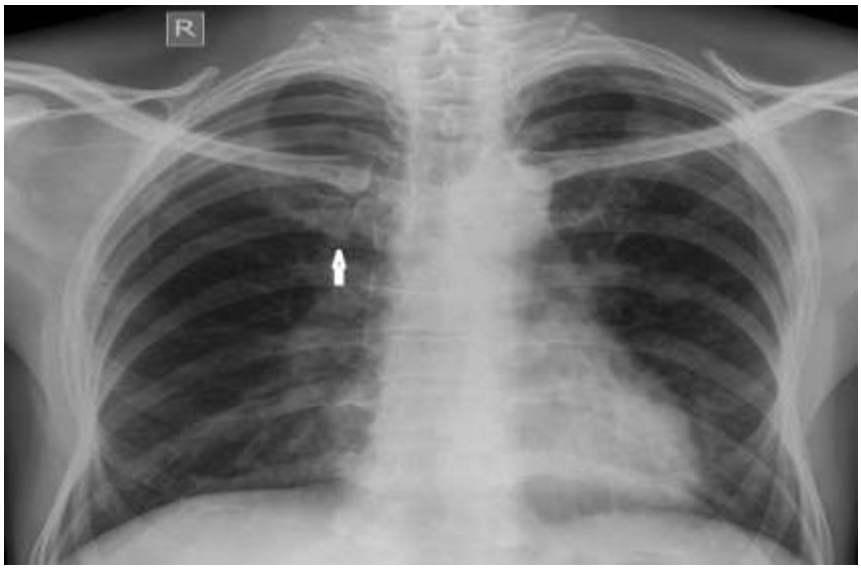


Fig 2: Chest Radiograph showing calcification





IV. Results

In our study, distribution of costal cartilage calcification in different age groups are 3 in the age group of 30-40 years (9%), 5 in 41-50 years (15%), 9 in 51-60 years (26%) &17 cases in 61 to 70 years (50%) (table 1, figure 1 & 2). Figure 3 shows distributions of costal cartilage calcification in male (56%) and females (44%). In different age groups, incidence of costal cartilage calcification in males are 10% in 30-40 years, 11% in 41-50 years, 26% in 51-60 years & 53% in 61-70 years. (table 2) In females are 7% in 30-40 years, 20% in 41-50 years, 27% in 51-60 years & 46% in 61-70 years (table 3). Table 7 shows the distribution of calcifications in different ranges of chest expansion are 20 cases of costal cartilage calcification in the range of 1-1.5 cm, 11 cases in 1.6-2 cm, 2 cases in 2.1 -2.5 cm & 1 in the range of 3.6-4 cm [3]. The same distribution in case of males are 10 cases in range of 1-1.5 cm, 6 cases in range of 1.6-2 cm & 1case in range of 3.6-4 cm. (table 8) In case of female the distribution are 10 cases in range of 1-1.5 cm, 5 cases in range of 1.6-2 cm & no cases were found in the rest of the ranges (table 9). The persons with chest expansion range below 1.5 cm had complains of dyspnea on exertion which can be contributed to the increased rigidity of chest wall since they were not suffering from any known lung disease like COPD or Ankylosing Spondylitis. The mean chest expansion was 2.331 with SD 0.827 with range of 1cm-4cm & Standard Error of Mean(SEM) 0.0832. Statistical correlation between costal cartilage calcification and chest expansion was done by Chi-Square test with yate's correction. Chi squared value was 19.042 with 1 degrees of freedom. Two tailed P value was <0.0001 by conventional criteria, it is statistically significant. (table 13). In case of males, the mean of chest expansion was 2.34±0.898 & SEM 0.128 with range of 1cm-4cm & Chi squared value 7.131 with 1 degrees of freedom. Two tailed P value is 0.0076. By conventional criteria, it is statistically significant. In case of females, the mean of chest expansion was 2.322±0.759 & SEM 0.108 with range of 1cm-4cm. Chi squared value 9.925 with 1 degrees of freedom. Two tailed P value is 0.0016. By conventional criteria, it was statistically significant.

V. Discussion

Calcification of the hyaline costal cartilages is known to occur with increasing age & with various diseased conditions. Costal cartilage calcification can affect the normal elasticity of the thoracic cage and decrease the range of chest expansion. Chest expansion can be measured in antero-posterior & transverse planes by special calipers. Circumferential measurement can be taken by a centimeter tape around the chest. Calcification of costal cartilages lead to decrease in "bucket-handle" movement of the ribs & decreased flexibility of ribcage. Exertional dyspnea in elderly people can occur due to this cause. Apart from the age group of 41-50 years, males are affected more than females in all age groups which is consistent with findings of Charles Teale (1989)[6]. King JB (1939) observed that calcification of costal cartilages is rare before age of twenty and occur with advancing age which is observed more frequently and more extensively in costal cartilage of first rib than others and established that the condition begins at an earlier age in the male sex. He reasoned that costal cartilage calcification is a physiological response of a connective tissue to the strains imposed upon it by muscular action to react towards greater rigidity of anterior chest wall following the assumption of upright posture [9]. McCormick (1980) examined radiograph of calcification of costal cartilages from chest plates of 210 cadavers and indicated a roughly linear increase in mineralization with advancing age. It is also observed that there are traces of costal cartilage calcification in all cadavers over the age of 25 years, moderate calcification in 40 years, dense calcification in only two individuals below the age of 55 years [1]. Charles Teale et al (1989) studied 700 chest radiographs, 100 (50 men and 50 women) from each of 3rd to 9th decades. He examined each radiograph to determine the site and extent of calcific changes in costal cartilages. He observed that prevalence of costal cartilage calcification increased from 6% in the 3rd decade to 45% in the 9th decade and was commoner in men [6]. Barchilor V (1996) studied the extent of costochondral ossification of the first rib from 78 chest radiographs of 13 healthy male soldiers subjected to a periodic follow-up. Radiographs were taken at a mean interval of 2.9 years over a fifteen-year period. His results showed that calcification of the first costal cartilage start early in adult life and progress at individual rates proceeding from the costal towards the sternal end of the cartilage. The morphological age related changes ranged from formation of small osseous islands in the cartilage to a complete ossification between the first rib and the sternum [35]. Pushpa MS in her study, showed there is an increase in grading of costal cartilage calcification of first rib with increase in age.

Vaziri et al, in their study showed that calcification of the costal cartilages cause significant reduction in rib movement and thoracic cage volume displacement. Costal cartilage and joint calcification generate a greater resistance against rib cage expansion. This increased resistance, imposes an increased load on muscles and may partially account for a sense of increased respiratory effort [33]. Moll & Wright in their study showed gradual decrease in chest expansion with increasing age [38]. The present study is corroborative with these studies.

VI. Conclusion

In the present study, the incidence of costal cartilage calcification in different age groups were studied which were 9% in the age group of 30-40 years, 15% in 41-50 years, 26% in 51-60 years & 50% in 61 to 70 years. In both male & female, costal cartilage calcification follows similar distributions with males (56%) being affected more than females (44%). In different age groups, incidence of costal cartilage calcification in males are 10% in 30-40 years, 11% in 41-50 years, 26% in 51-60 years & 53% in 61-70 years and that in females are 7% in 30-40 years, 20% in 41-50 years, 27% in 51-60 years & 46% in 61-70 years. Apart from the age group of 41-50 years, males are affected more than females in all age groups. In both genders, incidence of costal cartilage calcification was low in the age group of 30-40 years & gradually increased with age. The distribution of calcifications in different ranges of chest expansion are 20 cases of costal cartilage calcification in the range of 1-1.5 cm, 11 cases in 1.6-2 cm, 2 cases in 2.1 -2.5 cm & 1 in the range of 3.6-4 cm. The mean of chest expansion is 2.331 with SD 0.827 & Standard Error of Mean 0.0832 with range of 1cm-4cm. The same distribution in case of males are 10 cases in range of 1-1.5 cm, 6 cases in range of 1.6-2 cm & 1case in range of 3.6-4 cm. the mean of chest expansion was 2.34±0.898 and SEM 0.128 with range of 1cm-4cm. In case of female the distribution are 10 cases in range of 1-1.5 cm, 5 cases in range of 1.6-2 cm & the mean of chest expansion was 2.322±0.759 and SEM 0.108 with range of 1cm-4cm.

It shows that below the chest expansion range of 2.5 cm, the incidence of costal cartilage calcification increases significantly indicating its effect on chest wall rigidity. The persons with chest expansion range below 1.5 cm had complains of dyspnea on exertion which can be contributed to the increased rigidity of chest wall due to costal cartilage calcification since they were not suffering from any known lung disease like COPD or Ankylosing Spondylitis. Since costal cartilage calcification significantly reduces chest wall flexibility with increasing age and increases workload of respiration, it is an important factor to keep in mind in treating as well as during studying the chest X-ray of aged patients complaining dyspnea on exertion.

Limitations:

1. The sample size was small (50 men and 50 women)
2. Time period of the current study was short
3. CT Scan is not done during imaging

References

Journal Papers:

[1]. McCormick WF, Stewart JH. Age related changes in human plastron: Roentgenographic and A morphologic study. J Forensic Sci. 1988;33: 100-120.
[2]. Standring S. Gray's Anatomy.40th Ed.2013.1677
[3]. Pushpa MS, Roopa Kulkarni, and C Sheshgiri, Study of 1st Costal Cartilage Calcification on Radiographs in South Indian Population as an Indicator of Age of Human-Beings. Research and Reviews: Journal of Medical and Health Sciences. 2013: 2(3): 69-76
[4]. Datta A.K. Principles of General Anatomy 7th ed.2013. 54 ,69
[5]. Vastine JH et al. Genetic influence of osseous development with particular reference to the deposition of calcium in the costal cartilages. American J Roentgenol. 1948;59 (2): 213-221
[6]. Charles Teale et al. Calcification on chest radiographs: The Association with age. Oxford Journals – Medicine. Age and Ageing. 1989; 18(5):333- 336.
[7]. Grainger RG et al. 1992, Diagnostic Radiology: An Anglo-American Textbook of Imaging 2 nd ed., Churchill Livingstone U. K., pp 165-166.
[8]. Horner JL. (1949) Premature calcification on the costal cartilage,its frequent association with symptoms of non organic origin. Amer J Med Sci 218, 186–93. Page | 82
[9]. King JB. (1939) Calcification of the costal cartilage. Brit J Radiol 12, 2– 12.
[10]. E. Fischer, Verkalkungsformen der Rippenknorpel, Fortschr. Geb. Ro¨ntgenstr. Nuklearmed 82 (1955) 474–481.
[11]. W.U. Kampen, H. Claassen, T. Kirsch, Mineralization and osteogenesis in the human first rib cartilage, Ann. Anat. 177 (1995) 171–177.
[12]. Ontell FK, Moore EH, Shepard JA, Shelton DK. The costal cartilages in health and disease. Radiographics. 1997;17:571-577.
[13]. Nanci A. Enamel: Composition, Formation, and Structure. In: Ten cate's oral histology: development, structure, and function. 7th ed., Mosby, St. Louis, MO, USA; 2008. p.1 34-1 40.
[14]. Subrahmanyam BV. Personal identity. In: Modi's Medical Jurisprudence and Toxicology, 22nd ed., Butterworths, New Delhi, India; 2001 . p.53- 54.
[15]. Kerley ER. The microscopic determination of age in human bone. Am J Phys Anthropol 1 965;23(2):1 49-63.
[16]. Stewart JH, McCormick WF. A sex- and agelimited ossification pattern in human costal cartilages. Am J Clin Pathol 1 984;81 (6):765-9.
[17]. Rejtarová O, Hejna P, Rejtar P, Bukac J, Slí- zová D, Krs O. Sexual dimorphism of ossified costal cartilage. Radiograph scan study on Caucasian men and women (Czech population). Forensic Sci Int 2009;1 91 (1 -3):1 1 0.e1 -5. Page | 83
[18]. Leder B. Gonadal steroids and bone metabolism in men. Curr Opin Endocrinol Diabetes Obes 2007;1 4(3):241 -6.
[19]. I scan MY, Loth SR, Wright RK. Age estimation from the rib by phase analysis: white males. J Forensic Sci 1 984;29(4):1 094-1 04.
[20]. Russell KF, Simpson SW, Genovese J, Kinkel MD, Meindl RS, Lovejoy CO. Independent test of the fourth rib aging technique. Am J Phys Anthropol 1 993;92(1):53-62.
[21]. Yavuz MF, I scan MY, Cölo glu AS. Age assessment by rib phase analysis in Turks. Forensic Sci Int 1 998;98(1 -2):47-54.

[22]. Dennis E. Anderson, Brett T. Allaire and Mary L.Bouxsein. associations of costal cartilage calcification with prevalent vertebral fractures in older adults . Center for Advanced Orthopaedic Studies, Beth Israel Deaconess Medical Center, Boston, MA,USA . Department of Orthopedic Surgery, Harvard Medical School, Boston, MA, USA.
[23]. Luttgens K, Deutsch H, Hamilton N. 1992. Kinesiology , scientific basis of human motion. 8th ed. Dubuque, IA: Brown & Benchmark.
[24]. Smith JC, Mead J. 1986. Three degree of freedom description of movement of the human chest wall. J App l Physiol.60:928 – 934.
[25]. Agostoni A, Mognoni P, Torri G, Saracino F. 1965. Relation Between changes of rib cage circumference and lung volume. J Appl Physiol. 20:1179 – 1186. Page | 84
[26]. Grimby G, Bunn J, Mead J. 1968. Relative contribution of rib cage and abdomen to ventilation during exercise. J Appl Physiol. 24:159 – 166.
[27]. Loring SH, Mead J. 1982. Action of the diaphragm on the rib cage inferred from a force-balance analysis. J Appl Physil: Respirat. Environ Exercise Physiol. 53:756 – 760.
[28]. Mead J, Smith JC, Loring SH. 1995. Volume displacements of the chest wall and their mechanical significance. In: Roussos Ch, editor. The thorax, part A: physiology. Section 20, 2nd ed. New York, NY: Marcel Dekker Inc. p. 565 – 586.
[29]. Smith TC. 1997. Respiratory system: aging, adversity, and anesthesia. In: McCleskey CH, editor. Geriatric anesthesiology. Baltimore, MD: Williams & Wilkins. p. 85 – 99.
[30]. Rao NG, Pai ML. 1988. Costal cartilage calcification pattern – a clue for establishing sex identity. Forensic Sci Inter. 38:193 – 202.
[31]. Guo B, Liao D, Li X, Zeng Y, Yan Q. 2007. Age and gender related changes in biomechanical properties of healthy human costal cartilage. Clin Biomech. 22:292 – 297.
[32]. Lau A, Oyen ML, Ken RW, Murakami D, Torigaki T. 2008. Indentation stiffness of aging human costal cartilage. Acta Biomater. 4:97 – 103. Page | 85
[33]. Vaziri A. , H. Nayeb-Hashemia and B. Akhavan-Taftib. Computational model of rib movement and its application in studying the effects of age- related thoracic cage calcification on respirator y system. Computer Methods in Biomechanics and Biomedical Engineering. Vol. 00, No. 0, 2009, 1–8 34. Verma GL. Sex determination by costal cartilage calcification. Indian J Radiol. 1980;
[34]. Barchilor V. Hershkovitz I, Rothschild BM, Wish-Baratz S, Latimer B, Jellema LM, et al. et al. Factors affecting the rate and pattern of the first costal cartilage ossification: Am J Forensic Med Pathol. 1966;17 (3): 239-247.
[35]. Boruah Kritica et al. Effectiveness of thoracic core conditioning using stretch pole for community elderly with moderate copd- a single blind study.International Journal of Physiotherapy and Research, Int J Physiother Res 2014, Vol 2(1):394-02. ISSN 2321-1822
[36]. J Kim Chang-Beom et al. The effect of chest expansion resistance exercise on chest expansion &maximal respiratory pressure in elderly with inspiratory muscle weakness. J Phys Ther sci.2015Apr;27(4):1121-1124