Material and method

I. Radiological study of clavicle for age estimation in case of livings

A. The material for the study consists of -

- All the patients of age between 12-30 years both male and female, who were referred to the department of radio-diagnosis, PGI, Chandigarh for CT chest with any indication except bone development disorder or bone tumors or congenital bone disease, have been included in the study.
- Total number of 250 patients of each sex has been studied.
- Photocopy of birth certificate or any other document of birth proof has been retained as age proof of all the patients included in the study.

B. Examination method and technical considerations:

CT examination of chest has been performed in all patients for their own diagnostic purpose and data acquired on multi slice CT scan machine- Siemens’ Sensation-16 (Siemens Medical System, Foresheim Germany) using following parameters:

- KVP -120
- mAs -150
- Slice collimation -16x1.5
- Pitch factor-1.15
- Rotation time - 0.5sec.

The raw data acquired was reconstructed form the region of bilateral sterno-clavicular joints in the slices of 2mm/2mm thickness using a high resolution algorithm at bone (osteo) window setting (1500/300-450HU) and filter(b60f) suitable to view osseous structures by producing sharpness in the resultant images. Data has been acquired in single breadth hold with the slice collimation - 16x1.5, thereby avoiding motion artifacts from the
resultant images. No additional radiation dose has been given to the patient for the purpose of the present study. The volume-dose index (CTDi.vol) in all subjects was same, i.e. 10.50mGy as that for routine CT chest protocol in spiral CT i.e. not more than standard CT as pitch was used $\geq 1$.

**C. CT scan:**

Computed Tomography is the process of creating a cross sectional tomographic image of a 3 dimensional object by exposing it with X-rays from multiple projections and performing a mathematical reconstruction with the help of computer. Basically a fan shaped beam of X-rays scans across the patient in synchrony with an arc of detectors on the opposite side of the patient. Transmitted rays in sufficient number are received by the detectors at different angles of X-ray beam, depending upon the attenuation coefficients of the tissue traversed by beam at different levels and the final image representing various structures is reconstructed by computer applying various mathematical algorithms.

With the onset of advanced technology in the field of radiology fast CT scanner were introduced to meet the demand of modern diagnostic radiology and spiral CT, one of the great innovation was introduced by Dr. Kalender (1989). Spiral CT is based on slip ring technology that has permitted continuous gantry rotation with simultaneous couch increments like a spiral acquiring continuous data of predefined volume in single breath hold and images are reconstructed later on in the form of axial sections. It has been proved advantageous in proving benefits of --- 1) no motion artifacts, 2) improved lesion detection, 3) reduced partial volume effect, and 4) multi-planar Imaging. The disadvantages associated with these scanners are increased Image noise, reduced Z-axis resolution and increased processing time (Kalender, 1994a and 1994b; Mintz, 1994).

Further advancement in CT technology with the introduction of Multi slice CT was proved a holy grail in the field of radiology. MDCT (Multi Detector-row CT) represents
the latest breakthrough in CT technology because of its glimpsing features. It is a specialized CT system equipped with a multi detector array that simultaneously obtains topographic data at different slice thickness (Flohr et al., 2003). Slice thickness in MDCT is determined by detector width not by the collimator. Multi Detector-row CT scanners are equipped with dual slice, 4-slice, 16-slice, 64, 128 or 256-slice in single go acquisition. The fundamental differences between MDCT scanners lie in the detector array design. The advantageous impact of Multi-slice CT (MCCT) includes a significant reduction in scan time, reduced motion artifacts, improved resolution, ultra thin slices, faster acquisition in single breath hold, and volumetric acquisition for multiple reconstruction techniques. Fig 4.1 demonstrates the basic principle of CT and fig 4.2 gives some brief information about the advancements in CT technology.

D. Procedure:

Patient is positioned in the centre of the beam from above and below. Then first reference line is adjusted at the starting landmark of the scanning area and it is adjusted at level of root of the neck (7th cervical vertebra). A scanogram of chest is taken from with topo length of 512mm at 120kVp and 50 mAs. Then scanning volume is planned for CT chest right from 1st thoracic vertebra to 12th thoracic vertebra using parameters--- kVp-120, mAs- 150, rotation time 0.5 seconds, Pitch factor- 1.15, Slice collimation- 16X1.5 with the delay of 30 seconds from the start of intravenous contrast. Data acquired after this process is reconstructed according to the diagnostic requirement of patient. The same data has been retrospectively used for the evaluation of the ossification status of bilateral medial clavicular epiphyses after applying the parameters of bone evaluation i.e. reconstruction in bone algorithm, osseous filter and bone window.
Fig 4.1: Demonstrating basic models of CT:

A. Scanning Phase of CT

B. Data acquisition in CT

C. Image formation

References:

A, B and C- http://www.sprawls.org

D- www.sbmhealthcare.com/contactus.php
Fig 4.2: Demonstrating spiral CT and its advancement

A. Spiral CT principle,

B. MDCT Principle

C. Detector array in MDCT

E. Exclusion criteria:

- Any patient with known congenital or acquired bone disease.
- Patients without valid documentary proof of age (birth certificate/Driving licence/Identity card/passport/certificate of passed examination (govt. or affiliated school), etc.

F. Clavicle:

It is a long bone, curved like English alphabet ‘f’ in italics and lies horizontally in the upper and anterior part of the thorax, immediately above the first rib. It articulates medially with the manubrium sterni, and laterally with the acromion of the scapula. It presents a double curvature, being convex forward at the sternal end, and concave at the scapular end. Its lateral third is flattened from above downward, while its medial two-third is of a rounded or prismatic form.

The lateral third has two surfaces (upper and under) and two borders (anterior and posterior). The upper surface is flat, rough, and marked by impressions for the attachments of the Deltoides in front, and the Trapezius behind. Bone is subcutaneous between these impressions. A rough eminence, the coracoid tuberosity is there at under surface, which surmounts the coracoid process of the scapula, and gives attachment to the conoid ligament. An oblique ridge, runs laterally forward from the tuberosity, gives attachment to the trapezoid ligament. The anterior border is concave, thin, and rough, and posterior border is convex, rough, and thicker than the anterior.
Fig 4.3: Left clavicle. Superior surface

(Ref: Human Anatomy: Gray’s Anatomy on www.theodora.com/anatomy)

Medial two-third, the prismatic part, is curved so as to be convex in front, concave behind, and is marked by three borders, separating three surfaces. The anterior border is continuous with anterior margin of flat portion and is smooth between the attachments of the Pectoralis major and Deltoideus. The superior border is continuous with the posterior margin of the flat portion. It is smooth and rounded laterally, but medial third is rough for the attachment of Sternocleidomastoideus. The posterior or subclavian border extends from the coracoid to the costal tuberosity forming posterior boundary of the groove for Subclavius, and gives attachment to a layer of cervical fascia.

Fig 4.4: Left clavicle: Inferior surface

(Ref: Human Anatomy: Gray’s Anatomy on www.theodora.com/anatomy)
The lateral part of anterior surface facing upward is continuous with the superior surface of flattened portion. It is smooth, convex, and nearly subcutaneous. Lower, elliptical part gives attachment to Pectoralis major and upper to sternocleidomastoideus. The posterior or cervical surface is smooth, and looks backward. It is concave medio-laterally, and is in relation, with the transverse scapular vessels, brachial plexus of nerves and the subclavian vessels. It gives attachment, to part of the Sternohyoideus. It has one or two foramen, which transmits the chief nutrient artery of the bone. The inferior or subclavian surface is narrowed medially and is continuous with the under surface of the flat portion. It has a broad rough surface on medial part, the costal tuberosity for the attachment of the costo-clavicular ligament. The rest of this surface is occupied by a groove, which gives attachment to the Subclavius and coracoclavicular fascia. A longitudinal line dividing this groove gives attachment to inter muscular septum of the Subclavius.

The Sternal Extremity is triangular in shape, directed medially downward and forward. It articulates with the manubrium sterni through the intervention of an articular disk and inferiorly with the first rib. The circumference is rough, for the attachment of numerous ligaments. The Acromial Extremity, a small, flattened, oval surface directed obliquely downward, for articulation with the acromion of the scapula. The circumference is rough above, for the attachment of the acromioclavicular ligaments.

The clavicle consists of cancellous tissue, enveloped by a compact layer, which is comparatively thicker in the intermediate part and acts as a fulcrum to enable the muscles to give lateral motion to the arm. In the female, the clavicle is generally shorter, thinner, less curved, and smoother than in the male. In those persons who perform considerable
manual labor it becomes thicker and more curved, and its ridges for muscular attachment are prominently marked (Standring S., 2008).

G. Clavicular ossification:

Clavicle is the first fetal bone to undergo ossification by membranous ossification without prior endochondrial ossification, unlike the other long bones of human body. Ossification initially starts with two primary ossification centers, one lateral (trapezius deltoideal end) and other medial (sterno-mastoid pectoralis major end) during 5th and 6th fetal week (Ogden et al., 1979; Kumar et al., 1989). Cartilagenous growth areas (epiphysis) appear at both ends sternal as well as acromial. A secondary ossification center appears at sternal end to form a scale like epiphysis which begins to fuse between 18 to 25 years of age and is completely fused to diaphysis between 25 to 31 years of age (Mckern and Stewart, 1957). This is the last of the epiphysis of long bones to fuse. Of all the long bone in the human skeleton, it is the clavicle which displays the longest period of growth-related activity, rendering it particularly useful for the estimation of age at death in the earlier years (Black and Scheuer, 1996).

The slowly maturing flake like epiphysis at the medial end of the clavicle is useful in young adults. A clavicle with no evidence of fusion or fusing epiphysis is most likely to occur from an individual less than 18 years of age. A well defined fusing flake occurs in individuals between 24-29 years. Final fusion is unlikely before 22 years and is nearly complete by 30 years (Szilvassy,1980; Webb and Suchey,1985; MacLaughlin,1990; Black and Scheuer,1996). Because of the extended development period of the medial clavicular epiphysis clavicle can provide accurate age estimate of young adults (Todd and D’Errico,1928), which is helpful in forensic setting, as young adults constitute a large portion of forensic work. The relative timings of the epiphyseal development and its union with clavicular shaft may be used in estimating the age of osseous remains and data
suggests that detailed knowledge of maturation of medical clavicle could be useful adjunct in forensic age diagnosis of living as well as dead.

**H. Evaluation criteria:**

Data of the CT scans in all the patients evaluated on the basis of appearance of ossification centre and the degree of fusion of epiphysis and diaphysis of medial end of clavicle, separately for left and right side. The stages of maturity and union of the medial clavicular epiphysis has been categorized on the basis of the same criteria as used by Schmeling et al. (2004) as following

Stage 1- Ossification centre not ossified. The medial margin of the clavicle is concave before the start of secondary ossification till 14 to 16 years of age.

Stage 2- Ossification centre ossified, but epiphyseal cartilage not ossified. The secondary ossification center appears at the sternal end with a sleek like calcified process.

Stage 3- Epiphyseal cartilage partly ossified. Epiphyseal cartilage starts ossifying causing partial fusion of the ossification center with the clavicle.

Stage 4- Epiphyseal cartilage completely ossified, but fusion scar is present.

Stage 5- Epiphyseal cartilage completely ossified and scar is no longer visible. In the last stage sharp margins of bone are building up at the medial end of the bone (clavicle) with the disappearance of the fusion scar.

All these features of ossification status are well demonstrated in the fig 4.5 by CT images. To observe the inter-observer differences, samples at random were examined by the co-supervisor and no differences in ascertaining the stages were noticed.
Fig 4.5: CT scan images demonstrating the development stages of the clavicle:

A. Stage-1

B. Stage-2

C. Stage-3

D. Stage-4

E. Stage-5
II. Technique specific parameters:

A. Influence of slice thickness on interpretation of ossification stages:

1. Material:

CT scans of 100 subjects (55 males and 45 females) falling in the age group of 12 years to 30 years, originally performed for their diagnostic purpose as contrast enhanced CT chest, neck angiography, pulmonary angiography and bronchial artery angiography on 16 slice (Siemens Sensation 16) CT Scan machine, retrospectively analyzed to find out the ossification status of bilateral medial clavicular epiphyses at different slice thickness.

2. Method:

Volumetric data of the CT examination in all the patients was acquired using technical parameters—kVp - 120; MA - 140/150; Rotation time - 0.5sec; Pitch - 1.15; slice collimation- 16 x 0.75; FOV 294 mm; Matrix 512 x 512. The volumetric data acquired from spiral CT scans was reconstructed into axial scans of slice thickness - 1mm, 2mm, 3mm, 5mm and 7 mm using kernel B-60 (filter suitable for osseous structures) at window width / window level 1500 / 450 HU (window-osteo).

3. Evaluation criteria:

The respective ossification stages were determined corresponding to each slice thickness separately for both sides (Right as well as Left) in case of all the subjects involved, using the same classification criterion, as used in study of main parameters i.e. the criterion as used by Schmeling et al. (2004).

Stage 1 - Ossification centre not appeared.

Stage 2 - Ossification centre ossified, but epiphyseal cartilage not ossified.

Stage 3 - Epiphyseal cartilage partly ossified.

Stage 4 - Epiphyseal cartilage completely ossified, but fusion scar is still visible.
Stage 5 - Epiphyseal cartilage completely ossified and scar is no longer visible.

B. Comparative analysis of clavicular ossification staging as using CT and Digital X-ray:

1. Material:

CT scans and Digital X-rays of a patient population of 100 (55 male and 45 female) subjects falling in the age group of 13-30 years, coincidently preformed on same day, for their respective diagnostic purpose in the period 2008-2010, were retrospectively examined for finding the ossification status of bilateral clavicles for comparatively analyzing the data.

2. Method:

Both the techniques have been applied in each one of the subjects.

- CT scan of chest for all the subjects was performed on 16-row MDCT scan (Siemens sensation 16) of Radio Diagnosis Department of P G I M E R, Chandigarh using technical parameters -- kVp-120; mAs-150; Rotation time- 0.5 seconds; Pitch-1.15 and slice collimation 1.5x16. The slices of 2mm thickness were reconstructed at bone window-1500/450 HU (osteo) using kernel (filter) B60f.

- Digital x-ray of each one of the subjects was also performed on Philips flat panel detector (Philips Digital-diagnost Optimus- 50) digital radiographic system of Radio Diagnosis Department of P G I M E R, Chandigarh. The technique used ---- Posterio-anterior View of sterno-clavicular joints at high KVP (120) and using AEC(Automatic exposure control) technique for automatic adjustment of mAs (mili Amperes x seconds) according to the requirement of energy attenuation caused by body tissue traversing the X-ray beam while exposing the body part for
producing digital radiograph. This technique is adapted to the patient minimum and high latitude radiograph, so that it can be reconstructed according to visual perfection of the tissue for viewing bone, soft tissue, air filled lungs or cartilage. For viewing or studying bone development or bone abnormality we produce high latitude sharp film by using edge enhancement process. This all can be done during post processing accordingly from the same data which has been acquired while performing digital thorax X-ray of the patient. That means one does not have to expose the patient separately for different requirement (for analyzing the tissues with different attenuation (atomic number). This is the major advantage of digital radiography over conventional, where one can not change the image quality once it is produced. Patient dose is saved in this way.

The digital X-rays of the patients, originally done on the request of chest X-ray was reconstructed in the form of high latitude radiograph and increased sharpness in the film by using edge enhancement parameter to facilitate the proper viewing of bone margins clearly.

3. Evaluation criterion:

The ossification stages (the degrees of ossification) of the medial clavicular epiphyseal cartilage were assessed on the basis of classification criterion defined by Schmeling et al. (2004), as previously described in study of main parameters.

The ossification stages were evaluated for both the clavicles (Right and Left) in each subject on the basis of digital x-ray as well as CT scan.
C. Reduction of dose with the employment of AEC technique in CT protocols for clavicular ossification staging

1. Material:

The subjects included in the study were 100 in number irrespective of sex, falling in the age group of 12 to 30 years, as these subjects were those patients who came to the department for CT chest and their examinations were performed for their respective diagnostic purpose and were deliberately selected for finding the ossification status of medial clavicular epiphyseal cartilage. Another parameter, which was also kept under consideration, apart from the age group included in this particular part of study was Body Mass Index (BMI) of the subjects. The average body-built and underweight subjects (BMI≤22kg/m²) were selected for applying CARE Dose 4D technique for CT scanning, as no reduction in dose/mAs was observed in the subjects having BMI above 22kg/m².

2. Method:

Chest CT of 100(59 male and 41 female) subjects was performed using automatic exposure control (AEC) with reference mAs—150 on Siemens sensation -16 (16 slice) MDCT (Multi Detector-row CT) scan machine. All the other parameters were kept constant kVp—120, Pitch—1.15, and reference mAs was kept constant for all the subjects. This technique is termed as CARE Dose 4D in Siemens medical system. Height and weight of each subject was recorded before performing the scan and then corresponding values of effective mAs and CTDI<sub>vol</sub> were noted down for each subject.

3. Automatic exposure control (AEC) technique:

Currently X-ray beam modulation technique (adjustment of the X-ray current during scan) based on patient’s size and beam transmission is implemented by CT vendors in some modern MDCT scanners. This is an anatomy dependent attenuation based method of tube current regulation and allowed significant reduction in dose. CARE Dose 4D (in
Siemens, Malvern, Pennsylvania), Smart Scan (in General Electric, Milwaukee, Wisconsin), and SURE Exposure (Toshiba, New YORK) are commercial versions of this current modulation (Thomas, 2005). Automatic exposure control provides automatic tube current adaptation to the patient’s size and anatomic shape together with an on-line controlled tube current modulation for each tube rotation. Based on a user’s defined Image Quality Reference mAs, Care Dose 4D modulates the tube current on-line during each tube rotation according to the patients angular attenuation profile. With the setting of Reference mAs the image quality (image noise) can be adjusted according to the diagnostic requirement(Application Guide, Siemens Medical Solution, Sensation 16).

4. Body Mass Index (BMI):

The body mass index (BMI) is a statistical measure which compares a person’s weight and height. Though it does not actually measure the percentage of body fat, it is used to estimate a healthy body weight based on person’s height. BMI is defined as individual’s body weight divided by the square of his or her height. The formulae universally used in medicine produce a unit of measure of kg/m² (Eknoyan, 2008).

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\text{SI unit of BMI} = \frac{\text{mass (kg)}}{\text{(height (m))}^2}
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[mass in kilograms divided by square of height in meters]

The present study has been conducted on Siemens Sensation-16 to show the relationship of CTDI\text{vol} and mAs with body mass index of the patient in chest CT (with AEC technique) and to know the percentage of dose reduction with this technique as compared to conventional (fixed tube current technique) depending upon the BMI of the patient/subject.
5. Evaluation criterion:

Height and weight of each subject was used to calculate the BMI (Body Mass Index) of all the subjects included in the study and corresponding values of mAs and CTDI_{vol} were recorded for the same (BMI) in case of each subject, so that the reduction in CTDI_{vol} could be determined for each subject with specific BMI undergoing CT chest examination. Correlation of BMI with CT volume- dose-index (CTDI_{vol}) was calculated statistically by using Pearson’s correlation test and the percentage reduction in dose in comparison with fixed mAs technique was also calculated in each one of the subject.

Stages of ossification were evaluated on the basis of the classification criterion used by Schmeling et al. (2004) as used in main study, so as to show that the reduction in dose delivered to the subject achieved by using this technique has not resulted in deterioration of image quality in CT. ALARA (as-low-as reasonably achievable) concept has been implemented in CT protocol.