

Discussion

I. Radiological study of clavicle for age estimation

Development stages of medial clavicular epiphysis have been studied for a long time by so many groups of research scientists in the age group of legal relevance (12 to 30 years). They have adopted different approaches in different situations for finding the time interval of ossification status of medial clavicular epiphysis. A group of scientists has adopted anatomical approach through post mortem examinations (Stevensen,1924; Todd and Errico,1928; Mckern and Stewart,1957; Szilvassy,1980; Webb and Suchey,1985; Ji et al.,1994; Black and Scheuer,1996; Baccino et al.,1999). Whereas the another group has used radiological approach in living beings either X-rays or CT scans (Flecker,1933; Galstun,1937; Jit and Kulkarni,1976; Kreitner et al.,1998; Schmeling et al., 2004; Schulz et al.,2005; Schulze et al.,2006; Muhler et al.,2006; Schulz et al.,2008; Kellinghaus et al.,2010). In the recent years it is also being studied using modern radiation–free radiological techniques like MRI and ultrasound (Schmidt et al., 2007; Schulz et al., 2008; Quirmbach et al., 2009). It is still under consideration for debate whether the age intervals corresponding to different ossification stages defined by anatomical studies can be applied to X-rays or CT in case of living beings. Thus the requirement of radiological reference studies was felt to aid forensic age estimation in case of living individuals.

While comparing the results of different studies carried out on various ethnic groups, variable difference was found in the time span of appearance of secondary ossification center in most of the studies. For example, in present study, the onset of stage 2 was first noted at the age of 15 years in case of males and 14 years in case of females, whereas it was found between 11 to 13 years in reported studies (Fecker, 1933; Galsaun,
1937; Jit and Kulkarni, 1976; Kreitner et al., 1998) though of using different approach of examination. On the other hand a marked delay is reported in the appearance of stage 2 in the study conducted by Webb and Suchey (1985), which is earliest, observed at the age of 16 years. This might be assumed due to methodological problem, like the onset of calcification might be difficult to detect by anatomical section than by radiological methods. Fecker (1933) has mentioned that the longer duration of appearance of ossification center (stage 2) only reflects the problem in exact staging of maturation, due to overlaying soft tissue and bony structure. In the CT-based study by Schulz et al. (2005), the stage 2 was first noted at 15 years in both the sexes, which is in accordance with the earliest onset of male subjects in present study. The stage 2 in the study by Kellinghaus et al. (2010) was first noted at the age 14 years in male individuals and at the age 13 years in female individuals i.e. one year earlier in both the sexes than the present study. This indicates the need of separate studies for different populations.

The onset of stage 3, in present study was observed at the earliest at 15 years of age in both the sexes, by analyzing axial CT scans of 2mm thickness performed on same scanner. In 100% of the subjects, it was observed at 20 years in males and 19 years in females. In case of females, this bone was observed to be ossified one year earlier than that of males. No apparent difference concerning the onset of partial fusion (stage 3) of medial clavicular epiphysis was noticed, which is 16 to 19 years in all the studies (Todd, 1924; McKern and Stewart, 1957; Jit and kulkarni, 1976; Webb and Suchey, 1985). This development stage lasts considerably for longer period, as reported in some previous studies. For example, 18 to 30 years in the study by Mckern and Stewart (1957) and 17 to 33 years in another study (Webb and Suchey, 1985). This again might be assumed due to another methodological problem. Some persistent small grooves or notches noticed during anatomical preparation might be mistaken for partial fusions, whereas radiographic
assessment may ease out the proper visualization of complete fusion with clavicular shaft (Jit and Kulkarni, 1976). Kreitner et al. (1998), who have conducted the very first CT-based study in this regard, have noted the earliest onset of partial fusion (stage 3) at 16 years of age, but the study was considered with limited value, as the results were not separately analyzed for both the sexes and evaluation has also been conducted on thick slices (3-8mm) in most of the cases. The earliest age, at which stage 3 was detected by Schmeling et al. (2004) was 16 years in either gender, which is one year later than the onset of stage 3 in present study. The same stage was reported by Schulz et al. (2005) at the age of 17 years in males and at 16 years in female subjects, but the slice thickness in this study was also larger (7mm) in maximum cases. Kellinghaus et al. (2010), reported about the medial clavicular ossification staging revealed by using thin-slices performed on MDCT(Multi Detector-row CT), but the age intervals corresponding to the onset of stage 3 in their study was also same, as that of study by Schulz et al. (2005).

The crucial demand in forensic practice is the minimum age, at which ossification can be completed. In present study, the stage 4 was found in 92 male subjects and 74 female subjects. This stage was earliest observed in present study at the age of 21 years in males, which is in accordance with the data published by Schulz et al. (2005) and Kellinghaus et al. (2010) and at 20 years in females. The onset of stage 4 in present study has been found 1 year earlier in case of females than males, which is in agreement with the data given by Schmeling et al. (2004) in this regard. Some of the radiological studies have established 22 as minimum age for complete fusion of epiphysis (Flecker, 1933; Jit and Kulkarni, 1976; Kreitner et al., 1998). These age thresholds precisely seem to be in agreement with anatomical studies by Webb and Suchey (1985) and Ji et al. (1994), as the onset of complete fusion was reported earliest at 21 years in men and 22 in women (Webb and Suchey, 1985; Ji et al., 1994). Galstaun (1937) reported the beginning of complete
fusion at age 19 years, that too without discriminating in males and females and however, without differentiating between partial and complete fusion. But in these studies the complete fusion or total ossification of the epiphyseal cartilage was defined as final stage without considering the appearance or disappearance of fusion scar. Jit and Kulkerni (1976) insisted on the earlier diagnose of total fusion in anatomical examinations due to naked eye assessment of bones. Singh and Chavali, (2011) have documented on clavicles from anatomical samples that no clavicle had shown complete fusion until the age of 22 years in either sex. Garmendi et al. (2011) concluded that the complete fusion (stage 4& 5) of clavicle was found above 20 years of age in both the sexes as analyzed from digital X-rays.

The stage 5 was first reported by Schmeling et al. (2004) and it was characterized by complete fusion of the epiphyseal cartilage with disappearance of the epiphyseal scar. In this study, 26 years was the lowest age at which stage 5 was observed. This stage was given specific importance in this study for forensic age diagnostic process in case of living subjects in the context of criminal proceedings as it can be assumed that when this stage is reached, the subject must have attained the age of 21 at least 5 years prior to the examination. This is the reason why the examination of the clavicle is required to prove the age of a suspect above 21 years according to the recommendations of ‘Study Group on Forensic Age Diagnostics’ for criminal proceedings. This is basically required to increase the accuracy of the basic age examination process in this particular age group (18-21years). In present study, stage 5 was reported in 29 male and 41 female subjects and the earliest onset of stage 5 was noticed at 26 years in male subjects, which is in accordance with above mentioned data established by Schmeling et al. (2004) and Kellinghaus et al. (2010). But, the minimum age of the onset of stage 5 in present study is again observed one year earlier in females (at 25years) than males. This stage was first noted at the age of 22 in
case of males and 21 in females in the study by Schulz et al. (2005), and it was 4 to 5 years earlier than that of the reference study (Schmeling et al., 2004) using conventional radiographs. The partial volume effect in CT using thick slice for evaluation of stages was considered the possible reason of this early detection of stage 5. This apparent discrepancy concerning stage 5 classified by CT and X-rays was assumed to occur due to masking effect associated with the use of thick slice CT. In the study, by Kellinghaus et al. (2010), using thin slice CT scan images for the evaluation of ossification status of medial clavicular epiphysis, the earliest age of the occurrence of this stage 5 was noticed 26 years in both the sexes.

In present study, a standardized CT technique is used keeping all parameters constant in each one of the subjects included in the study, so that all possibilities of causing errors in the results could be eliminated. The slice thickness was kept constant for all the subjects involved in the study, which is 2mm it {was not standardized in some of the above mentioned studies like 4 different slice thicknesses (7mm,5mm,3mm,2mm and1mm) are used in the study of medial clavicular ossification staging by Schulz et al. (2005)}. The slice thickness used in the study published by Kreitner et al. (1997) was also varied from 1-8mm in 380 subjects. In other words, it is justified to say that no importance was given to this factor to bring about consistency in the results. The results would obviously vary when viewed at different slice thickness. Kellinghaus et al. (2010) has also used different slice thickness for the evaluation of staging in different subjects, but they have used ultra thin slices of the order of 0.6 mm, 1mm, 1.25mm and 1.5mm for evaluation, hardly leaving any possibility of yielding fallacious results. Table 6.1 presents a comparative data on ossification stages and age range reported in present study and earlier studies.
Table 6.1: Comparison of present study with earlier studies dealing with the ossification of medial clavicular epiphysis by using radiological techniques (X-ray or CT)

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample size (total= male+female)</th>
<th>Sex separation</th>
<th>Age range (years)</th>
<th>Method used</th>
<th>Ossification stages/ age range(years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kreitner et al., (1998)</td>
<td>380=229+151</td>
<td>No</td>
<td>0-29</td>
<td>CT/slice thickness (1-8mm)</td>
<td>11-22</td>
</tr>
<tr>
<td>Schulz et al., (2005)</td>
<td>556=417+139</td>
<td>Yes</td>
<td>15-30</td>
<td>CT/slice thickness (1-7mm)</td>
<td>15-23</td>
</tr>
<tr>
<td>Schulz et al., (2006)</td>
<td>100=50+50</td>
<td>No</td>
<td>16-25</td>
<td>CT/slice thickness (1-10mm)</td>
<td>16-24</td>
</tr>
<tr>
<td>Kellinghaus et al., (2010)</td>
<td>592=214+298</td>
<td>Yes</td>
<td>10-35</td>
<td>CT/slice thickness (.6-1.5mm)</td>
<td>13-20</td>
</tr>
<tr>
<td>Present study (2011)</td>
<td>506=254+252</td>
<td>yes</td>
<td>12-30</td>
<td>CT/slice thickness 2mm</td>
<td>14-19</td>
</tr>
</tbody>
</table>
Fig 6.1(a): Demonstrating earliest age of the onset of stage 2 & 3 in both the sexes in present study:

A: Stage 2

15 years, male

14.25 years (14 years and 3 months), female

B: Stage 3

15.9 years (15 years and 11 months), male

15.6 years (15 years and 7 months), female
Fig 6.1(b): Demonstrating earliest age of the onset of stage 4 & 5 in both the sexes in present study

C: Stage 4

21.5 years (21 years and 6 months), male

D: Stage 5

26.4 years (26 years and 5 months), male

25.5 years (25 years and 6 months), female
Fig 6.2(a): Demonstrating latest age of the appearance of stages 1&2 in both the sexes in present study:

A: Stage 1

17.9 years (17 years and 11 months), male

B: Stage 2

18.11 years (18 years and 1 months), male

17 years, female

18 years, female
**Fig 6.2(b):** Demonstrating latest age of the appearance of stages 3&4 in both the sexes in present study

**C: Stage 3**

25.25 years (25 years and 3 months), male

25.9 years (25 years and 11 months), female

**D: Stage 4**

29.75 years (29 years and 9 months), male

30 years, female
The comparison of the mean age corresponding to different ossification stages in case of male and female subjects was carried out by applying Mann Whitney and student t-test. The p value of Mann Whitney and student t-test for corresponding ossification stages shows that the mean age differences in male and female subjects for stage 1 and 2 are statistically significant. For stage 1 comparison was found highly significant with p value=0.002 in both the tests and for stage 2 also, it was highly significant with p=0.008 in t-test and 0.010 in Man Whitney test. The appearance of stage 1 is completed an average 11 months earlier in female subjects than male subjects and stage 2 also appeared an average 10 months earlier in females than males. In case of male subjects, stage 2 was first noted at the age of 15 years and in case of females at 14 years. For stage 3 the statistical significance is reduced for comparison of mean age in both the sexes with p value=.068 in t-test and p=0.092 in Man Whitney test. The difference between the mean age of males and females is reduced to 8 months at this stage, first appearance of this stage was observed 10 months later in males than females. For stages 4 and 5 no statistically significant differences (p values) were found on an average (mean age) age in both the sexes, whereas the first appearance of these stages was found earlier in females as compared to males.

The development differences between left and right clavicle were observed in 6 instances (1.6%) among 380 subjects in the study reported by Kreitner et al. (1997). Schmeling et al. (2004) revealed this maturity gap between left and right clavicle in 0.6% of cases, which was not statistically significant. These differences were observed by Schulz et al. (2005) observed these differences in 10.5% of all cases and results were not presented separately for each side. The development differences between left and right were observed by Kellinghaus et al. (2010) in 31 cases (6.2%) and they have chosen the side showing more advanced development stage for evaluation. Singh and Chavali (2011) found no significant difference in the development stages of ossification between left and
right side in both the sexes while evaluating ossification status from bones. In present study, the ossification stages have been determined separately for each side (both left and right) in each one of the subject and differences in development stage for both sides was observed in 68 (30 male + 38 female) cases among total 506 subjects and that accounts for 13.5% of the total evaluated sample. These differences were most commonly observed in stage 2 and 3, 3 and 4 for both sides. The stage was found to be advanced for both left as well as right side, so immaterial to say, that which side shows development faster than the other. The advanced stage is considered for statistical analysis of data in each case, more emphasis in the study has been given on earliest onset of each stage and side is not a matter of concern. The bilateral asymmetry observed in the ossification staging results has been demonstrated in the table 6.2 for present study as well as some relevant studies.

Table 6.2: The development differences observed in different studies between left and right clavicle

<table>
<thead>
<tr>
<th>Study</th>
<th>% in The development differences between left and right clavicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kreitner et al., (1997, 1998)</td>
<td>1.6% cases of total sample</td>
</tr>
<tr>
<td>Schmeling et al., (2004)</td>
<td>0.6% of total sample</td>
</tr>
<tr>
<td>Schulz R et al., (2005)</td>
<td>10.5% of total sample</td>
</tr>
<tr>
<td>Kellinghaus et al., (2010)</td>
<td>6.2% of total sample</td>
</tr>
<tr>
<td>Present study</td>
<td>13.5% of total sample</td>
</tr>
</tbody>
</table>

The present study has involved the subjects belonging to north India (Punjab, Haryana, Utter Pradesh, Bihar, Jammu and Kashmir etc). Since it has been stated in the literature published that ethnic origin does not exert any notable influence on the rate of
ossification within a particular age group (Schmeling et al., 2000a and 2000b, 2004), the
data of present study can be applied to the members of all ethnic groups in age
determination practice. The socio-economic status of the sample, on the other hand, does
have a decisive impact on the pace of ossification (Schmeling et al., 2004). There would be
chances of underestimation of age if reference values drawn from socio-economically
advanced population are applied to the subjects belonging to relatively low socio-economic
background, but in criminal proceedings this would not end up into a derogatory situation
for the individual concerned (Schmeling et al., 2006). The data of the present study has
been collected from mixed population of north India. Thus, it is relevant for a country with
same socio-economic status, as that of India. Moreover the study in this regard has been
conducted on Indian population after about 25 years in case of living subjects, as the earlier
study of age estimation in case of living beings, from clavicular ossification was conducted
II. Technique specific parameters

A. Influence of slice thickness on the determination of ossification status:

Computed tomography was used for the first time to study the ossification status of medial epiphysis of the clavicle by Kreitner et al. (1998) analyzing retrospectively the CT scans of the patients falling in the age range of 0-29 years. Slice thickness was not of course the matter of concern, as the status was analyzed retrospectively from chest CT examinations. The slice thickness used in their study for analysis was 8mm in 202 cases, 5mm in 88 cases, 4mm in 54 cases and 1-3mm in 36 cases. They recommended ideal slice thickness of 3mm for imaging of sterno-clavicular joint using pitch factor 1.3 to 1.7 with 3 mm reconstruction increments and table speed of 4 to 5 mm per second. Though, they did not mention the quantum of error while various slice thicknesses were used.

Schulz et al. (2005) later on made constructive efforts to evaluate the CT scans of 629 patients aged between 15 and 30 years, retrospectively, to find out the ossification status of medial clavicular epiphyseal cartilage. The slice thickness used in this study was also varied between 1-7mm. Maximum number of the cases were evaluated with 7mm (546 cases) and a few cases were seen on thin slices i.e. 5 mm (2 cases), 3 mm (4 cases), 2mm (1 case only) and 1 mm (3 cases). Thus effect of the slice thickness on the interpretation of the stages in such type of data evaluation could not be commented upon. Even then the slice thickness of 1 mm was recommended in authors’ opinion in the study.

The findings of present study are in conformance with this. It has been found in the study that 1mm and 2mm slice thickness of CT scan images yield identical results and either of this can be used in CT to get the best results without any error for the purpose of defining medial clavicular ossification stages. Muhler et al. (2006) determined ossification
stages of 40 live subjects at different slice thickness reconstructing the data acquired into CT images of 1, 3, 5 and 7 mm thick slices and found different stages while assessing at different slice thickness. They concluded that the slice thickness has a crucial impact on the evaluation of clavicular ossification status and found that even the slice thickness of 1 and 3 mm led to different results in one case. The ossification status was also found to be different in three cases using slice thickness of 3 and 5 mm for staging and same differences were encountered for slice thickness of 5 and 7 mm in another three cases. They suggested in the end to use slice thickness of 1 mm for CT examination of clavicle to evaluate the ossification stages for forensic age estimation purpose.

In order to ensure maximum accuracy in forensic age estimation practice, it is recommended to perform thin-slice CT scans. Thus thin-slices of bilateral clavicles performed on Multi Detector-row CT (MDCT) in case of the individuals aged between 10 - 35 years were analyzed successfully in 502 cases using the classification criteria of staging used by Schmeling et al. (2004) in a retrospective study (Kellinghaus et al., 2010). The findings of their study were in line with the other CT based studies on clavicle except from the fact that stage 5 first occurred at the age of 26, which is 5 years later as compared to the other studies by CT (Schulz et al., 2005), but with thick slices (7 mm). This vast difference assumed to occur due to partial volume effect with thick-slice CT images by a visual deception of the epiphyseal scar occurring with stage 4.

The present study was conducted on 100 live subjects aged between 12 to 30 years, evaluating ossification stages at different slice thickness (1 mm, 2 mm, 3 mm, 5 mm and 7 mm) and found that the results for different slice thickness were different in 25 cases among all (Table 5.7). As evident from the table, the differences in results were noted less in number at 3 mm slice thickness (only 7 cases), but increased significantly with the increased slice thickness and the cases with disagreement in the results raised up to 25 in
number at 7mm slice thickness. This difference in results depending upon slice thickness was mainly caused by partial volume effect and decreased resolution using greater slice thickness. The resolution along longitudinal axis is inversely proportional to the slice thickness, as when the slice thickness increases the resolution is decreased. These effects appear on the resultant images of CT and partly or fully mask the fine anatomical structures like cartilaginous epiphyseal plate creating confusion between stage 2 and 1 or epiphyseal scar creating confusion between stage 4 and 5. Sometimes, it was difficult to clarify whether the epiphyseal plate has been fused completely or not yet appeared, while defining the stage from 5 or 7 mm thick slice.

Thus it can be concluded that 2mm is the ideal slice thickness to be used for performing CT of bilateral sterno-clavicular joints for the purpose of finding ossification stages of medial clavicular epiphysis to attain 100% accuracy in the results and to keep balance between radiation dose delivered to the subject and the image quality. The reduction in slice thickness beyond the requirement is of no use, as it mandates the use of higher mAs (tube current x seconds) to increase CNR (contrast to noise ratio) in CT image which results in increased patient dose. Thus, there is no use of reducing slice thickness beyond 2mm, as the results were found to be identical for 1 and 2mm slice thickness in this regard. Then, why to increase patient/subject dose for nothing?

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

Radiological assessment of ossification status of the medial clavicular epiphyseal cartilage becomes essential to assess the age of living subjects, who are assumed to be at least 18 years of age, as it is the only long bone of human skeleton to retain its predictive
value as an age indicator till 30 years of age. The other indicators (ossification of hand and wrist, mineralization of third molar teeth and roots of wisdom teeth) have become inactive by this time (Klaus and Claus, 2005).

This part of the study has been carried out to find out, which is the more suitable technique for finding the medial clavicular ossification status in case of living beings, among all available radiological techniques, which have been successfully employed so far in this particular context. The degree of ossification was studied in case of living beings by Jit and Kulkarni (1976) using radiographic technique (X-rays). They tried to clarify some of their queries and difficulties regarding staging by using some anatomical samples. Later on the similar study was conducted by Schmeling et al. (2004) retrospectively analyzing the plain chest radiographs of 873 subjects. The reliable assessment of the degree of ossification of the medial clavicular epiphyseal cartilage in 174 out of 873 X-rays was not possible on both sides due to the overlaps or some other factors.

Kreitner et al. (1998) have discussed the problems in finding out the ossification status of medial clavicular epiphyseal cartilage with different techniques in case of living beings and concluded that CT is the better modality in providing vastly improved clarity in the visualization of fine details of anatomical structures separately for bones, soft tissue as well as cartilage without the superimposing of other structures lying in that region like ribs, vertebrae and other mediastinal shadows as in case of conventional radiographs. The conventional radiographs are often suboptimal likely due to inaccurate technical factors and processing of the films but all these problems were eliminated in the present study as digital radiographs used here are advantageous in modifying the quality of the image by post processing according to the requirement. High latitude images with edge enhancement technique are good to facilitate the dominated view of bones. This feature provided in Digital Radiography with the use of high kV_p (peak kilo-Volt) technique is adapted to keep
the patient dose minimum and to produce high latitude radiographs. Such radiographs can be reconstructed according to visual perfection of the tissue for viewing bone, soft tissue, air filled lungs or cartilage. In spite of all this, the problem of misinterpretation due to overlapping of other tissues could not be rectified in radiography. All these problems could be eliminated with the use of CT.

A comparative study of medial clavicular ossification staging, using X-rays and CT (both in the same patient) was conducted by Schulz et al. (2008) involving 57 subjects (53 males and 4 females) above 18 years of age for age estimation. The reliable assessment of ossification status was not possible in 15 clavicles out of total 114 clavicles (57x2) and results were not found in agreement in 2 clavicles out of total assessed 99 clavicles with both the modalities. The divergent results in both the cases with CT and X-ray were found in right clavicular ossification status which was classified as stage 2 by CT and stage 3 by conventional radiography. But in present study the interpretation was not possible in 12 (3 right + 9 left) clavicles out of total 200 (100 bilateral) clavicles with digital X-ray and the results were divergent in 37 (21 right and 16 left) clavicles out of total 188 clavicle, those analyzed successfully with both the modalities. Schulz et al. (2008) have used conventional radiographs in their study, while in present study Digital Radiographs are used. For CT the only difference found in used parameters was that of slice thickness i.e. 1mm in their study and 2mm in present study. They found differences in results with CT and X-rays in analyzing stage 2 and 3, but in present study, the difficulty in the interpretation is also faced in analyzing stage 1 and 2 in 3 (1 right and 2 left) clavicles, stage 2 and 3 in 8 (5 right and 3 left) clavicles, stage 3 and 4 in 7 (4 right and 3 left) clavicles, between stage 4 and 5 in 15 (8 right and 7 left) clavicles and stage 3 and 5 in 4 (3 right and 1 left) clavicles.
While comparing the published data of CT based study (Schulz et al., 2005) with that of conventional radiography based study (Schmeling et al., 2004), age correlation with regard to stage 5 was found to be problematic, as this stage was reported 5 years earlier in CT study than in the corresponding conventional radiography study. In a later study by Kellinghaus et al. (2010) it was first observed at 26 years of age which is in accordance with the data of conventional radiography(Schmeling et al., 2004). The problem might have occurred due to larger slice thickness (7mm by Schulz et al., 2005). Muller et al. (2006) have justified the effect of slice thickness on ossification staging, because fine anatomical structures may be partially or completely masked due to partial volume effect. In the present study, the slice thickness of 2mm is used presuming that the chances of error while analyzing ossification stages at 2mm slice thickness are minimized. The slice thickness of 2mm has been documented as the maximum recommended thickness for the CT scan, for the purpose of clavicular ossification staging so as to get maximum accuracy in the results (Kaur et al., 2010).

The image generation technique in both the modalities is different as X-rays, may be conventional or digital, give us two dimensional information and the structures lying in anterior and posterior plane are superimposed on each other in two dimensional radiography image, but CT gives us three dimensional(3D) view of the structures lying in different planes. This is the reason due to which three dimensional parts of our body can be studied without superimposition in CT. This is analogous to the problem encountered in the present study while comparing the results of two studies. One advantage of conventional or digital radiography over CT is its higher resolution (Rothschid et al., 2001), but superimposition of other skeletal structures is however, a major disadvantage for preventing the proper assessment of ossification status. CT is therefore considered a better technique for studying the three dimensional structures without superimposition.
The purpose of this study was to give comparative analysis of the performance of these two modalities in the assessment of clavicular ossification status. Because of superimposition problem, it was not possible to assess the staging of clavicular epiphyseal ossification in 11 cases (3 right and 9 left clavicles = 12 total clavicles) out of 100 bilateral (=200) clavicles with digital radiography and results were not identical in 37 clavicles out of 188 (97 right +91 left) clavicles assessed successfully with both CT and digital X-ray. The differences found in results were also felt due to superimposition problem. In one case, partial fusion could not be seen and the ossification stage defined with radiograph as stage 2 was defined as stage 3 in CT, stage 4 on CT was defined as stage 3 on X-ray in the other two cases, stage 4 on CT was given stage 5 on digital X-ray in seven cases and stage 3 on CT was reported as stage 5 with digital X-ray in three cases. All this was due to the differences in application of these two techniques in different location of body tissue/organ. So it is clear from the discussion, the reference data from CT studies should only be used for determination of ossification stage from CT and that of X-rays should be used for the evaluation of stage from radiograph. The bar graphs (figure 5.11) shows that the stages evaluated on CT are underestimated as well as overestimated with digital X-rays in some proportion of the sample for both the sides, right as well as left side in all the 5 stages. The only and most likely reason for the difference in the results of CT and X-rays is the prevention of the proper visualization of the ossification status on X-ray whereas CT provides clear and better visualization of ossifying cartilage as compared to digital radiograph.

Symmetric Measures of biostatics were calculated applying Chi-square test to find out the Spearman Rank Correlation and the Level of Agreement between the results of two techniques used in the study. The value of Spearman Rank Correlation was found +ve and above 0.5 for both sides (0.872 for Rt clavicles and 0.919 for Lt clavicles), thus there
is a +ve and highly significant (p= 0000) relationship in these two results. The results were also found in substantial agreement (Dawson and Trapp, 2004) for both sides of clavicular ossification stages (‘Kappa’= 0.715 for right clavicles and ‘Kappa =0.766 for left clavicles.

C. Reduction of dose with the employment of AEC technique in CT protocols for clavicular ossification staging:

Today with the capability of performing rapid multi-phasic studies, and increased use of the CT, the cumulative patient dose is rising up. Thus, there is a requirement of good radiation dose management in CT instead of performing CT studies with standard one-size-fit-all technique protocols (Haaga et al., 1991). Now the attention of the users has been drawn on implementation of as-low-as-reasonably–achievable (ALARA) concept into CT protocols (ICPR, 1982). ALARA principle says that patient should not be exposed to any radiation that is not required for producing an image of diagnostic quality (Thomas, 2005).

The radiographic technique used in CT i.e. mAs setting should be no higher than required to keep the noise to a level that will adversely affect the diagnostic interpretation. Absorbed dose in tissues from CT are among the highest observed in the diagnostic radiology (ICRP, 2002). These doses can often approach or exceed levels known to increase the probability of cancer (Pierce et al., 1976). Patient doses in CT depend primarily on design characteristic of the scanner, choice of radiographic technique (kVp and mAs), size of the patient and volume being scanned as, patient dose is directly proportional to mAs and scan length (Kalra et al., 2004).

The dose increases in supra-linear manner with increasing X-ray tube voltage (kVp). Pitch ratio is also one of the important factors to influence the patient dose in spiral CT and it is inversely proportional to patient dose (Thomas, 2005). Ideally the tube voltage
should be set to ensure an adequate CNR (contrast to noise ratio) for given imaging task. CNR can also be adjusted by changing the mAs accordingly (Huda et al., 2002). The scanning parameters for a given examination need to be adjusted carefully by the operator to ensure that the image quality is optimized, but the patient exposure doses are kept to a minimum. This trade off of image quality, radiation dose and diagnostic quality is a constant balancing act. The trade off in increasing pitch is an increase in effective slice thickness, which results in volume averaging and reduced image signal (McNitt-Gray, 2002, 2003).

Many technological innovations have been introduced in the modern CT scanners for radiation dose reduction. AEC represents the most critical development in CT technology for optimizing radiation exposure. Applying automatic exposure control (AEC) technique (based on weight, age, and indication for scan) to chest CT scan can reduce patient radiation exposure up to 20% according to a study (Prakash, 2010) presented at the ARRS (American Roentgen Ray Society), 2010. AEC is a technique that helps in individualizing the scan protocols for every patient depending on patient size. Individualizing of the scanning protocols can reduce dose through optimization of dose, because the patient size varies greatly. It is also important in the examination of children and small adults (FDA, 2002). The advent of automatic exposure control for CT scanners has eased the task of scanning parameters individualization and enabled dynamic modulation of tube current (Kalra et al., 2004).

The value of tube current has been selected as 150 mAs for fixed current technique in the present study (main study) because all the routine CT chest are generally performed at this value in department of radio-diagnosis (PGIMER, Chandigarh), presuming an ideal value of this parameter for an average build patient and this quality is readily accepted by all the radiologists in all the indications. The same value of reference mAs in AEC
technique is therefore selected for comparison purpose in this parameter of study. After the assessment of image quality, visualization of structures in lung, level of noise and severity of artifacts in reduced dose CT, the authors suggested that the dose could be reduced by reducing tube current to 110-140 mAs without significant degradation image quality (Mayo et al., 1995; Prasad et al., 2002; Ravenel et al., 2001). A considerable reduction of patient dose in the range of 35-60% can be achieved by using AEC technique in CT protocols especially in young adults and pediatric patients (Soderberg et al., 2010). Dose reduction of 53-65% was acquired in a study with the reduction of mAs from 115 or141 to 77 or 94 mAs, with a slight reduction in image quality but no significant difference in diagnostic accuracy was found (Shah et al., 2005). Gomi et al. (2008) carried out a study to determine the optimal scan conditions of using automatic exposure control (AEC) technique in low dose CT chest screening in order to achieve consistency in the image quality without increasing collective dose. They achieved improvement in image quality without increasing collective dose by using CT-AEC with the dose-reduction-wedge under low dose scan conditions.

The present study has been conducted on 100 patients for chest CT-examinations using CARE Dose 4D technique (AEC provided in Siemens sensation-16 MDCT system) in small size adults and young adults (with BMI ≤ 21) for the purpose of studying ossification status of medial epiphyseal cartilage under fixed reference mAs and other parameters. BMI of all patients was calculated from their height and weight, and corresponding mAs and CTDIvol recorded in each case. The relationship of CTDIvol and BMI was found to be highly significant (p ≤ 0.001). A considerable reduction in dose (more than 50%) depending upon the BMI of patient has been achieved using this technique without deteriorating quality of scans as compared to fixed tube current (mAs) technique (employed in the main study), because reference mAs was kept constant in order
to provide consistent image quality. Reference mAs should not be adjusted to the individual patient size. This value of reference mAs, 150 mAs in present study has been selected taking the reference of several published studies which have shown that above 140 mAs used in CT chest, the subjective assessment of image quality was indistinguishable by the radiologists (Mayo et al., 1995; Ravenel et al., 2001).

The technique has been proved beneficial in reducing patient dose in terms of CTDIvol for performing CT examination of young adults and small-size adults and that is very important in this age, as normal body tissues are more sensitive to dose effects in growing age. It is specifically important to use this technique in case of females for performing CT scan of bilateral clavicles or chest region, as axillary tissue of breasts are also being exposed to ionizing rays in this particular situation.