Review Article

Age Estimation from Ossification of Clavicle: A Comprehensive Review

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Abstract

Age estimation in cadavers, human remains and living individuals may have clarity issues with significant legal and social ramification for individuals as well as for the community. The current status of forensic age estimation in livings is mainly considered for the purpose of criminal prosecution to determine whether a suspect without valid identity documents has reached the age of criminal responsibility (criminal liability threshold of 21 years) and whether general criminal law in force for adults applies for that individual. In order to demonstrate that the proband has attained the criminal liability threshold of 21 years of age an additional x ray examination or CT scan of the clavicles is recommended along with physical examination, an x-ray of left hand and dental examination including orthopantogram to know about the dental status of the offender, because the other systems on which the development analysis is based generally mature fully by this time. The present work is a thorough review of the state of the art of estimation of age from clavicle.

Keywords: *Ossification; clavicle; age.*

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Introduction

The clavicle is a long bone with no medullary cavity like other long bones and first fetal bone to undergo ossification by membranous ossification without prior endochondrial ossification, like other long bones. The ossification initially starts with two primary ossification centers, one from medial end and other from lateral end during 5th and 6th fetal week.[1,2] Cartilaginous growth areas (epiphyses) appear at both ends i.e. acromial as well as sternal, transforming the development pattern to combination of endochondrial ossification and membranous ossification. Clavicle displays the longest period of growth related activity than any other long bone of human skeleton, thus rendering it useful for age estimation in early years. Clavicle can be used as age indicator even at puberty as it retains its predictive value when other growth related

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indicators have become inactive and remains an age indicator later up to the age of 30.[3] The relative timings of the epiphysis development and its union with clavicular shaft may be used in estimating the age of osseous remains, in cadavers as well as in case of living individuals.

Ritze-Timme et al.[4] has described age estimation in cadavers, human remains and living individuals. They concluded that any method used for age estimation should essentially fulfill the following specific demands - (1) they must have been presented to the scientific community by publication in peer-reviewed journals, (2) clear information concerning accuracy of age estimation by the method should be available, (3) method needs to be scientifically accurate and (4) principle of medical ethics and legal regulations have to be considered in case of age estimation in living individuals. The current state of forensic age estimation of living subjects is mainly considered for the purpose of criminal prosecution, to determine whether a suspect without valid identity documents has reached the age of criminal responsibility and whether general criminal law in force for adults applies for that individual.[5] In order to increase the diagnostic accuracy of estimating age in criminal proceedings, physical examination of the individual, an x-ray examination of hand, as well as a dental examination including dental x-ray to find out the status of dentition should be performed in each case and if the skeletal development of the hand is complete then x-ray or CT (Computed Tomography) scan examination of clavicles should be carried out. CT scanning is rather well suitable to determine the stage of epiphyseal union of the medial clavicle for age estimation during adolescence and the 3rd decade of life.[6] Schemling et al.[7] has described that according to the recommendation of study group for forensic age, diagnostic age estimates in criminal proceedings should be based on the general physical examination, the x-ray examination of hand and odontological examination by dentist and orthopantogram. In order to demonstrate that the proband has reached the age of 21 an additional x-ray examination or CT scan of the clavicles is recommended. Klaus and Claus[8] conducted a study of age estimation in adolescents and adults in crime proceedings on German population using all the examinations recommended by German study group of forensic age diagnostics (AGFAD) which included physical examination of the suspect, a dental examination, x-ray of left hand and radiography of medial end of clavicle. Mineralization of root of wisdom teeth is finished by the age of 21, however, radiological assessment of clavicle in both the genders showed lowest age at which stage 5 (non scar of fusion) was observed is 26 years. Garamendi et al.[9] performed following tests to confirm chronological age of 114 immigrant Moroccan males between age group of 13 to 25 years: general physical examination, corpus x-ray (Greulich and Pyle method) and dental orthopantomography (Demirjian method). Corpus x-ray (skeletal age) was most useful followed by Dermirjian's method (dental age) for chronological age of over or under 18 years. They concluded that the combination of skeletal and dental age variables represented a significant improvement in the prediction of the chronological age of the subjects in this population, reducing the number of ethically unacceptable test errors to a minimum. Schmeling et al.[10] has presented the updated recommendations about the study group on age diagnostics for criminal proceedings in order to increase the diagnostic accuracy and to improve the age estimation examination; an x-ray of hand, as well as a dental examination including dental x-ray to find out the status of dentition should be performed in each case.

Relative timings of the ossification of clavicle and the clavicular ossification as an age indicator

A secondary epiphyseal ossification centre at the medial end of the clavicle during adolescence in

the form of scale like epiphysis begins to fuse between 18 to 25 years of age and is completely fused to the rest of the bone between 26-31 years of age.[11] This is the last epiphysis of long bone to fuse. Clavicle displays the longest period of growth related activity than any other long bone of human skeleton, thus rendering it useful for age estimation in early years. 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 have come from an individual less than 18 years of age. A well defined fusing flake occurs in individuals between 24-29 years. Final fusion is likely before 22 years and is nearly complete by 30 years.[3,12,13] Based on large systematic studies the data shows that 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 medial clavicle end could be a useful adjunct in forensic age diagnosis of living as well as dead, but not all epiphyses are of equal value in estimating age. The best indicators were the epiphyses of proximal humerus, distal radius, iliac crest and medial clavicle.[11,13]

For a long time it was believed that the fusion of the clavicular epiphysis with the rest of the bone takes place between 20 and 25 years. McKern & Stewart[11] showed that the fusion of the epiphysis in American males commenced at 18 years and no case of complete union could be seen before the age of 25 years and found that the epiphyseal union of clavicle have five stages (0 to 4) and 30th year is the latest age likely to show epiphyseal activity as clavicle in some individuals are still active. The complete fusion is reported as early as by 22 years.[14,15] Warwick & Williams[16] stated that secondary centre of sternal end of clavicles appear in late teens and even early twenties and fusion take place quickly thereafter but reliable figures on this subject are not available. The radiographic staging of ossification of the medial clavicular epiphyses were comparatively assessed by Schulz et al.[17] using conventional radiographs and computed tomography for age diagnostics of 57 individuals undergoing criminal proceedings and they concluded that conventional radiographic reference studies should be used for staging by conventional radiography and CT reference studies should be used for ossification staging by CT. The studies using radiation free imaging technique to estimate age from the clavicle have been introduced so far are- (1) Magnetic resonance imaging (MRI) of sterno-clavicular joins of dead bodies aged between 6 and 40 years performed by Schmidt et al.[18] to define the ossification status of medial clavicle and the data of the study was proved to be comparable to existing data from the studies based on CT scans. (2) Ultrasound of subjects on the time course of clavicular ossification have been carried out in living subjects above 18 years of age by Schulz et al.[19] and proved that the age intervals corresponding to the ossification stages defined were consistent and comparable to the known data of CT and radiographic assessment.

Correlation of age with epiphyseal development stages using different techniques

Age estimation studied by many workers based on epiphyseal union degrees or pattern, using bone specimens, radiographs, CT and MRI have found it as a useful age indicator in early years.

Using bone specimens (Dead)

Epiphyseal union of anterior iliac crest and medial end of clavicle were studied by Webb & Suchey[13] in 605 males and 254 females in modern Americans aged between 11 to 40 years. Analyzing the union in terms of four stages he found that epiphyseal union of medial clavicle in modern Americans' sample starts earlier in

females than in males and complete fusion occurs at 20 years in females and at 21 years in males. Females' standard can vary 1-2 years from those of males but in general epiphyseal ossification timing in both the sex is just similar. Sternal end of right clavicles of Japanese aged between 13 to 31 years autopsied during 1982 to 1992 were studied by Ji et al.[20] to find out ossification stages. To define the degree of union, the 5 stages used by McKern & Stewart[11] were applied to the samples and found that, in females, union appears to proceed faster than in males. Comparing the present data with that of American males by McKern & Stewart[11], they concluded that union in Japanese males proceeds faster than that of Americans and the clavicles are suitable for estimating age from adolescence to about 30 years old. Schaefer & Black[21] proposed that wherever possible, appropriate standard of epiphyseal union of clavicle should be devised for more accurate aging reflecting population specific profile, as Bosnian males' clavicles start and attain complete union 1 to 3 years earlier than those of Americans.[11]

Using radiological techniques (Living)

The age intervals corresponding to different stages of ossification status on anatomical samples were studied later on in case of livings using radiological techniques to establish reference to be used in living individuals.

i) Using radiographic technique

Medial ends of clavicles examined radiologically by Jit & Kulkarni[22] in 684 individuals (391 males and 293 females) between the age group of 11 to 30 years from Punjab and Haryana and found that ossification centers appear between 11 to 19 years in females and 14 to 19 years in males, and the difference is statistically insignificant. The earliest partial fusion in both sexes occurs at 18 years of age and latest by 23 years. The earliest complete fusion was found to be at 22 years in males and 23 years in females and 100% instances showed complete fusion between 24-25 years in females and 25-26 years in males. Radiological assessment of the degree of ossification of the medial clavicular epiphyseal cartilage in young adults using chest radiographs in 873 patients was done by Schemling et al.[23] They concluded that the earliest age at which stage 3 (partial fusion) was detected in either gender was 16 years. Stage 4 (total fusion) was first observed in women at 20 years and in men at 21 years and in both genders stage 5 (disappearance of scar) was at 26 years, and a lateral view should be taken to facilitate age estimation to avoid the overlapping to other bones. It was reported that the problem was faced due to the difficulty in the interpretation of staging because of the overlapping of other bones like ribs, vertebrae, etc. on the medial ends of the clavicles in radiographs. Olze et al.[24] reported that though mineralization of third molar is usually completed by the age of 19-20 years of age, this feature cannot be relied upon when a person attains the age beyond 21 years. Therefore, an additional x-ray examination of the medial clavicular epiphyseal cartilage is strongly recommended.

ii) Using CT technique

The ossification status of medial end of clavicles of the patients with the lack of a bone development disorder below 30 years of age was analyzed using CT retrospectively by Krietner et al.[6] to establish a reference population for the stages of epiphyseal union. He concluded that CT is well suitable to determine the stage of epiphyseal union of the medial clavicle and rather may become a generally accepted method of age identification during adolescence and the 3rd decade of life. CT images of 629 patients aged between 15 to 30 years were retrospectively analyzed by Schulz et al.[25] and they reliably determined the ossification status of

the medial epiphysis of clavicle of 566 cases, using classification of stages used by Schmeling et al.[23] In both sexes stage two was first noted at age 15, stage 3 in males at age of 17 and in females at age 16, stage 4 in both sexes at age 21 and stage 5 was first noted in female subjects at 21 years and in males at 22 years of age which is 4 to 5 years earlier than observed using conventional radiographs. The partial volume effect in CT using thick slices could be avoided by reducing slice thickness up to 1 mm. Schulze et al.[26] analyzed CT scans of 100 patients (50 male and 50 female) between age of 16 to 25 years to establish a relationship between the age and the ossification of medial epiphysis of clavicle and concluded that a reconstruction kernel suitable for osseous structure should be used and images should be viewed or presented in bones window. He concluded at the end that CT of medial epiphysis of the clavicle would only be suitable for age estimation around the age of 21.

Variables affecting the staging of ossification

Muhler et al.[27] has shown the influence of slice thickness in CT scan on the assessment of clavicle ossification in forensic age diagnostics. The data acquired was reconstructed into the CT scan of the slice thickness of 1, 3, 5 and 7 mm and the ossification stage were determined for each reconstructed slice thickness. In one case the slice thickness of 1 mm lead to a different diagnosis of the ossification stage than a slice thickness of 3 mm, in three cases the diagnoses differed between the slice thickness of 3 and of 5 mm, and in another three cases, between 5 to 7 mm. It was concluded that for age estimation purposes, the slice thickness should be 1mm to ensure maximum accuracy and diagnostic reliability. Paine & Brenton[28] suggested that the measurements based on healthy cases may not be comparable in an analysis of individuals with poor diet and health. Lynn et al.[29] combined the data on clavicle fusion from different studies and applied a binomial logistic regression analysis aiming to assess whether or not variables such as sex, socioeconomic status and ethnicity influence the probability of having mature i.e. completely fused clavicles at a given age. It was explored whether the method of clavicle examination i.e. diagnosis from either a dry bone specimen, an examination of x-ray or an examination of CT scan, affect the accuracy of age determination from clavicular ossification and concluded that only ethnicity did not significantly affect the result.

Radiation free imaging techniques to find out ossification status

Schmidt et al.[30] conducted a study on MRI of 54 sterno-clavicular joints of the dead bodies aged between 6 to 40 years for age estimation from medial clavicular ossification and proved that the data was comparable to existing data from CT scan. All of the examined medial clavicular epiphyseal cartilages permitted the assessment of degree of ossification. The observed age intervals of the respective degrees of ossification correspond to the known data from x-ray and CT scan examination. It was suggested that the achieved results should be examined with a large number of cases and a modified protocol of MR examination.

Schulz et al.[19] carried out ultrasound studies on the time course of clavicular ossification for forensic age estimation in the living subjects above 18 years of age for the establishment of the radiation free imaging technique for assessment of clavicular ossification. Right clavicles of 84 subjects between 12-30 years of age were prospectively evaluated by means of ultrasound. Ossification stage classification was possible in 80 out of 84 clavicles. The earliest ages of respective ossification stages were 17.1 years for stage 2, 16.7 years for stage 3 and 22.5 for stage 4. The age interval for these stages was consistent and comparable to the known data from CT and

radiographic assessment. Evaluation of medial clavicular epiphyseal ossification by ultrasound could ultimately be a rapid, economic and non-ionizing diagnostic modality for forensic age estimation.

Comparative analysis of the applicability of methods

Schmidt et al.[30] performed a comparative analysis of the applicability of skeletal age determination methods of Greulich-Pyle and Thiemann-Nitz for forensic age estimation in living subjects. For this the skeletal age of 649 hand x-rays from German subjects aged 1-18 years was determined by both the methods. Both were reported to be equally suited for forensic age diagnostics. Accuracy of both methods was determined based on regression and measures of certainty. The degree of acceleration in the reference population of two methods was calculated as the mean difference between the estimated skeletal age and the actual age of the test subject. Compared to Greulich-Pyle population, the Thiemann-Nitz population was accelerated by 0.44 years in both males and females. The conclusion was, if the subject has come from a population with a high acceleration status, the Thiemann-Nitz method should be used to prevent overestimation of age. Schulz et al.[17] conducted a study on radiographic staging of ossification of the medial clavicular epiphysis and comparatively assessed conventional radiographs and computed tomography scans of sterno-clavicular joints used to perform forensic age diagnostics in 57 individuals undergoing criminal proceedings. With CT, it was possible to determine the ossification status of all clavicles but in case of conventional radiography reliable assessment was not possible in 15 out of 114 clavicles studied due to the superimposition of other structures. The staging results were identical in 97 out of 99 clavicular epiphyses in two cases; however, ossification was classified as stage 2 by CT and 3 by conventional radiography. Regarding stages 4 and 5, both methods produced identical results in all cases. In forensic age estimation practice, it is necessary that conventional radiographic reference studies should be used for ossification staging by conventional radiography and that CT reference studies should be used for ossification staging by CT. Further studies in dead bodies are required to issue recommendations as to whether conventional radiography in 3 planes or CT should be method of choice for the assessment of clavicular ossification. Cardoso[31] compared the timing of epiphyseal union in the postcranial skeleton in recent sample of 121 individuals, between ages of 9-29 years with data from the scapula, clavicle, humerus, radius and ulna. Epiphyseal union was scored at 16 anatomical locations, using 3 staging schemes - 1) no union, 2) partial union and 3) complete union. He concluded that in upper limb the epiphyses of elbow are first to fuse (11 to 15 years of age) followed by those of shoulder and wrist. In scapular girdle coracoids' are followed by the glenoid surface and remaining epiphyses, with medial clavicle fusing last by the age of 25 to 27 years.

Cortical index which is defined as the proportion of cortical thickness to the total diameter of the bone was calculated in 210 adult clavicles of North-West Indians (128 males and 82 females) concluding that from 15 to 30 years of age it increased in both the sexes but thereafter steadily decreased with an initial sharp decrease in the age group of 31-40 years in both the sexes. After the age of 40 years this rapid decrease in the index continued in females but become slow and gradual in the males. Bilateral differences were insignificant but sexual difference was significant in age groups from 41 years onwards being decreasing continuously in females and gradually in males.[32]

Rogers et al.[33] evaluated the presence of rhomboid fossae as sex and age indicator for unidentified skeletal remains using a large contemporary sample (N=344:113 females, 231 males). Logistic regression found significant relationship between the presence of a rhomboid fossa and age. Fossae were common in males than in females. A fossa on

right clavicle is indicative of male with 81.7% probability whereas a fossa on left is indicative of a male with 92.2% probability. Younger individuals more commonly exhibited rhomboid fossae than older ones; the largest fossae were most common in males of 20-30 years of age. However the age effect was not conclusive and must be corroborated by other methods. A test of sex estimation method on an independent sample (26 males, 23 females) found nine males and only one female with fossae present on left clavicle. When a clavicle exhibits a rhomboid fossa, it is likely to be from a male. The greater difference in fossae expression between sexes on left clavicle makes the use of left bone preferable.[33]

The incidence of an articular facet on the coronoid tubercle of the clavicle was studied indicating the presence of coraco-clavicular joint in the paired clavicles observed from 1000 adult subjects aged 18 to 95 years (748 males, 252 females) and 75 children (45 males, 30 females) of known age. The paired clavicles from 50 neonates and 35 fetuses were examined. The facet was absent in the fetuses, neonates and young children, the youngest clavicle showing facet was from a girl of 13 years (bilateral). In adults the incidence of facet was 10.1% (bilateral 5.7%, unilateral 4.4%) in males and 8.3% (bilateral 3.6%, unilateral 4.8%) in females.[34]

Conclusion

Clavicle displays the longest period of growth related activity than any other long bone of human skeleton, thus rendering it useful for age estimation in early years. Clavicle can be used as age indicator even at puberty as it retains its predictive value when other growth related indicators have become inactive and remains an age indicator later up to the age of 30 years. The relative timing of the epiphysis development and its union with clavicular shaft may be used in estimating the age of osseous remains, in cadavers as well as in case of living individuals.

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