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Musculoskeletal radiology

European Radiology

Review article

Bone age determination based on the study of the medial extremity of the clavicle

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Aistraci. The development of the medial clavicular epiphysis and its fusion with the clavicular shaft have been a subject of medical research since the second decade of this century. Computed tomography provides the imaging modality of choice in analyzing the maturation process of the sternal end of the clavicle. In a retrospective study, we analyzed normal development in 380 individuals under the age of 30 years. The appearance of an epiphyseal ossification center occurred between ages 11 and 22 years. Partial union was found from age 16 until age 26 years. Complete union was first noted at age 22 years and in 100 % of the sample at age 27 years. Based on these data, age-related standardized age distributions and 95% reference intervals were calculated. Compared to the experience recorded in the relevant literature, there are several landmarks that show no significant change between different ethnic groups and different periods of publication; these are the onset of ossification, the time span of partial union, and the appearanate of complete union. Despite the relatively long time spans of the maturation stages, bone age estimation based on the study of the development of the medial clavicular epiphysis may be a useful tool in forensic age identification in living individuals, especially if the age of the subject is about the end of the second or the beginning of the third decade of life (e.g in determining the applicability of adult or juvenile penal systems). Another possible use is in identifying human remains whose age is estimated at under 30 years.

Key words: Clavicle - Medial clavicular epiphysis - Computed tomography - Bone age determination

K Kreciiier

Introduction

The clavicle is a long bone with a medullary cavity and the first fetal hone to undergo primary ossification. l-lowever, unlike oiher long hones, it initially does this h' membranous ossification without prior endochonciral ossification. There are two primary ossification centers. One medial and one lateral, which appear during the 5th and 6th weeks of intrauterine life and normally coalesce during fetal life [1. 21, Cartilaginous growth areas (epiplivses) develop at both the acromial and the sternal end of the clavicle, transforming the developmental pattern 1o a combination of endochondrial longiiudinal ossilication and membranous diaphyseal/meaphyseal ossification. However, the most active growth thïouglíout postnatal development remains diaphyscal mc n branous ossi 'canon [2].

A secondary epiphvseal ossification center appears at the medial end of the clavicle during adolescence. The analysis of its development and its fusion with the clavicular shall has been at the center of interest since the seeondclecade of this century [3-61. Based on large, systematic studies. it has been shown that the relative timing of the epiphvseal development of the medial clavicle and Is union with the clavicularshaft may he used in estimatjig the age of osseous remains. These data suggest that detailed knowledge ofthe maturation ofthe medial clavicle could be a useful adjunct in the forensic age identiuieattoil of living or dead individuals 17. S].

In our own department, we have observed an increasing need over the years for age identification of living individuals. In the vast majority of cases, the suspeeled age range as between late adolescence and the thuU decade of life- In addition to conventional radiogriphs of the left hand and the pelvis, we used the stage of epiphvseal development of the medial clavicular epipins>, determined by computed tomography *(Cr).* for age etlrnation [1]

The purpose of this article is to present our reference population for the stages of epiphyseal maturation and LtT1]Ofl of the medial clavicle determined by Cl' and to

compare these data with those obtained [rum the area - tomica I, anthropological. and radiological literature - Another objective is to assess **Ill,** extent to 'hi'll this method can he used for age est mat ion in li I jig intl i id- ads. and thus lo tie line its potential role in forensic age identification.

Examination methods and technic-at considerations

There are several examination tech iii q ties I or i'naa the sternal end of the clavicle in the I nout, individual Conventional radiograph - which were the basis of anal - ysis in some comprehensive studies (Table 2) 5-S. 10-121. are often suhupt I mal he Ca use of c,ve flapping ribs, ye ne hrae and med jasti nal shadows [13-15]. In some cases these structures even prevented the exact determination of the stage @1 medial cpiphvseal del el - opment 110, II. Conventional multidireclional tomog- raphy may he helpful. but it is time-consuming and the images often lack clan!.

Computed tomography cli mi flat es neon (lithe pri h - ems associated with conventional radiugraph and to- mography. The aim ul a ti e exposure t r dcii at ion is low - Cr than ill tomography, and it provides vast k better an a - tomic pictures. In addi t!on. it visual i/es soft tissue It lie lu es [IS. 161 Coin pare ci to standard CT. spi [a ICE tee h - nique offers se\- era I advantages. the [101 important he - ing the short examination time, w hic h increases its aL - ceptance by the patient With spiral CT. it is possible acquire coat i nuotis data during it single bre at h-hold. thereby av (lid ing respiratory notion art ci acts, Hove', - ci', with the exam i nat Ic in ol sm 111cr vOIDiiies tn spiral CF. a higher volume-dc se index is to he expected in comparison to that of standard ('T [I 7]. This problem can be so1 ccl by using pitch factors greater than I For imaging of the stertioclavic ula r joints with spiral (T technique. we consider a 3.0-lure col in] a tion. a table speed of 4-5 mm/s (pitch 1.3 -I.?), and a 10 trial recon- struct ion increment su ffici en t For better assessrn cii t of bony structures, a high-resolution reconstruction algo- rithm is recommended 1161.

The sternoelavmcularjoints are ilso.tirciethIc to "hag- I -■— resonance (MR) imaging II II i p until flOW, lit) data exist conce ru i ng tire MR appearance of the cli ftc'- cot stages of the developmiient of the mediaL ciac icular cpiphvsis. Howev Cr, wit h regard to forensic. legal and ethical aspects. the use of a radiation-expnsure-tree un aging moda Ii o, would he of great advantage 1191

The Mainz reference population

Due to an increasing need lot age esiinotLon of III ng individuals in if,, course of criminal proced ares, we he - gan to examine the maturation of the medial clavieiilau epiphysis by (1 a an adjunct to X - ray cxarraneuloaus 01 the hand and pelvis.

In order to perform a svstC nat Ic a nal\MS of medial clavicular de c iopnie mit - the CT exam nat ions of the chest or shou der girdle froni a 7.5-year period (Sept ciii - her 1989 to March 1997) were retrospectively reevaluat- ed by an experienced radiologist. Basic Conditions for further analysis were patient age of under 30 years lack of bone development disorders, and sufficient docu- nientation of the sternociavicular joint region. The lat- ter had In allow assessment of the medial clavicular epi- phvsis in a hone window setting (15041/30() flU). mdc- pelidctltl\ trout the originally chosen reconstruction al- gorithrti. All CT examinations were performed on scan- ners of (lie third or fourth generation (Somatom DRH. Pitis and Pius S. Siemens, Erlangen, Germany: Picker PO 2000 and 5004). Picker International, Cleveland. Ohio. USA), The CT data were acquired by using either a conventional standard mode or a spiral mode with var\ ing pitch factors (1-2). according to the examina- tion prot (bet) I used for the specific indication. Effective slice thickness of the sternociavicular joint region was S nini in 202 eases (53.2%). 5mm in 88 cases (23.2%). I d 4 n,ni in 54 cases (14.2%). In 36 cases (9.5%). slice thickness ccas either 1,2 or 3mm.

[lie indications for the CF examinations were a tu- mor in 192 cases (0.5 %) trauma of the thorax or the shoulder girdle in 69 cases (18.2 0%), followed by infec- tious diseases in 34 cases (8.9%). In 85 cases (22.4%). the indications for ('I varied: for example, determina- non itt the seoltosis angle inpatients with kyphoscoliosis (ii = i$). diseases of the heart or great vessels *(n* = 12). acute or chronic recurrent pulmonary embolism (ii = 11 . pneumothorax In 10), and interstitial lung diseases (n ':9)

ci accordance with the studies by Owings Webb and Myers Suche and by lit and Kulkarni 18. 121, the stages of maturity and union of the medial clavicular epiphysis Were categorized as follows: Stage I refers to nonunion ithout ossification of the epiphysis. Stage 2 describes nonunion hut is i th detect able ossification of the epiphy- sis. Stage 3 wts defined as partial union, and stage 4 as complete union of the ossified epiphysis with the clavic- ular tnetaphysi.s. Osseous union was considered partial until there was complete time attachment of the whole epiphvsis to the metapt documented by CT.

The age of the individuals at the time of the CF cx- amination was known in all cases. Age was handled in strict cii ro miologieal terms: thus, age IS years refers to pursoris having reached their 15th but not their 16th hi rtli day.

Based on the assumption of normal empirical distri - at ions of the developmental stages, statistical analysis comprised the calculation of stage-related standardized are distributions that allow for determination of a 95 Uoconfidence interval for each developmental stage. At the same time, the probabilities were calculated as having it certain maturation stage at a given age.

To date, the CT.scans of3SO patients under the age of 30 years hale been available for further analysis. The sample consists of 229 males (602%) and 151 females ($9. <°u). Analogous to standard X -rays of the left hand, the age distribution of the whole sample in dependence on the developmenial stage of the left medial clavicular epiph sis is give'] in Table 1: nonunion without ossifica- on of tie ned al e pip hysis (stage I) could he observed

Table I. Ace JistrIhulLoli ul ndiuduik ɪ' ike tLge ot ,n,ltLir.Iiupn iii ei,i'icular = 38U)

Age (years)	SIgcL I	–	Suge C	Siage N UI	Stigc 4 Ii (%)	Total
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IS			Ia (39%)	V 14 1 %	-	17
11)			S (25Th	iS 173%)	-	20
20			I (5%	21 Q5%		22
21				II i%)	-	IS
22			¦ IN	I1	1 (6%)	16
				12 1 5%)	III	22
24				6 1%	14(7(1%)	20
'S				S (! %)	'ç($5%)	34
			.	217%)	25c3%)	27
27	--				I7(1110%)	I?
2X					23(1(1 ⊐■	23
29	.-				13 (UXI%)	13
total	75 Ci]% I		7(1(1.5%'	1113 (2"!..	13233%)	380

until age 16 years Fig. 1) The appearance of an ossi fica- ɪon center in the media I e pi ph Isis (stage 2)occurred be - tween ages II and 22 years (Fig.2). Parlial union (stage *3)* was found from age 16 until age 2 ears (Fig. 3). Complete union (stage 4 was First noted it(age 22 years and in l0(1% of the sample at age 27 seats (Fig. 4). Determination of the malLITMIOn stage by CT is a simple method: the cmIv possible diagnostic pitfall be- ing the persistence of the medial epi phs Sca Ossi lieu! loll center that was once reported in a case report f201.

Di fiere ices in development hetceli ɪlie left and right medial cliv icula r e piph Yses CrC noted in is cases (1.6%). However, this did not lead to any statistically significant iii sac pa icy in the maturation Process he - ɪwee n both sides. There were no St a list ica E iv significant differences in epiphvseal de' elopment between males and females and, in iew of the Ii1nited sample size, the results were not eoiiicle red Se para tel).

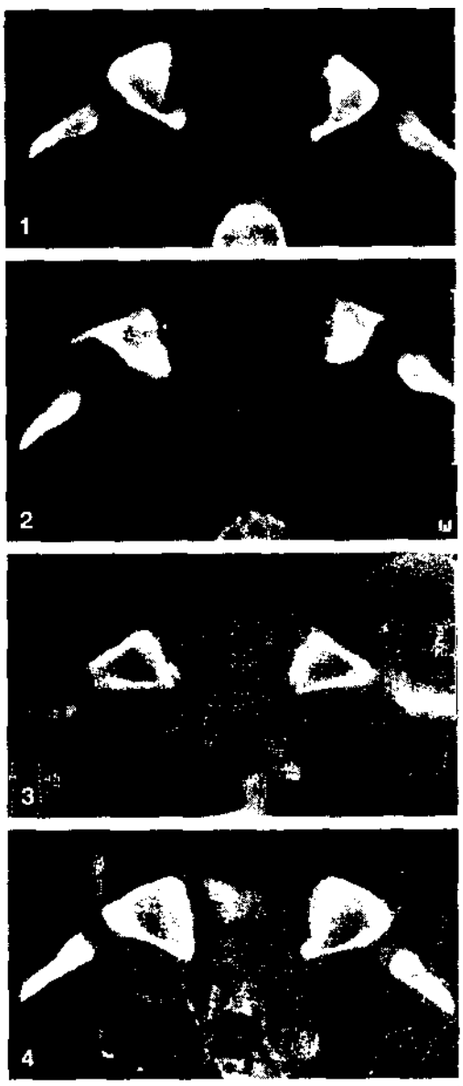
In Fig. 5. the prohahitilies of a Certain niaturatlon stage concurring with a given age are represented. At the same Inc. tlicN enable the detertilination of a 9S reference interval for each dcv ci opine in at stage: ɪflee the mean age of appeara nec of the ossification od the nic- dial epiphvi s (stage 2) was 16. I years aid the st :tnda ret deviation 1 9 sean, the 95% intc[val extends ɪ ruIn 12.3 to 19,9 years. For stage 3. the interval emends I ram 16.5 to 25.5 years itIi a mean of 20.9 sears md a staiidarcl de- viation of 2.2 "ears. For stage I, it extends from (I to In years. and for stage 4 it begins vith age 22 years.

Comparison with other studies

The postnatal de elopment of the clavicle and especial- ly of the medial cIa i cut 'a r e pi plivsis has been wider ill- vestigatlon For a long time [3-8. I U—I 21. In Table 2, the nitisi comprehensive studies from the literature current- ly a' ailuible are summarized, In comparing these data it h those of our population. several points need to be CO nifli nted on.

Despite different ethnic groups and publication peri- ods, the time span of the appearance of the secondary ossification center (beginning between age II and age 13 years), shows no significant difference in all the sam- ples but two. In the group studied by Owings Webb and Air ciS Stlehey (SI, there is a marked delay in appearance of the ossificailon center. This maybe due to a method- ological problem, namely that the onset of calcification (ii the medial epiphsis may he more difficult to detect h' anatomical section than by radiological methods (ra- diographs or computed tomograph)). Recker men- tioned in his studies (6. 101 that, due to overlaying soft tissues and bony structures, an exact staging was not possible in many of his individuals. Thus, the longer lure of appearance of secondary ossification only re - ¦ eels his problems in the exact staging of the maturation I the medial el avieul a r end.

There are also no apparent differences concerning the on'et of partial fusion of the medial epiphysis in all the studies (age 16 to 19 years). However, this develop- mental stage lasts considerably longer in the studies by MeKer,i and Stewart 11 and by Owings Webb and My- ers .Suehev [8] Again. one may speculate whether this re fleets another methodological problem. Persistent small grooves or notches seen during anatomical prepa- rat on in av he classified as partial fusions, whereas ra- dit'raphie studies may yield complete fusion of the epiphvsis orth the clavicular shaft (21]. However, to date no comparative study exists that deals with this problem



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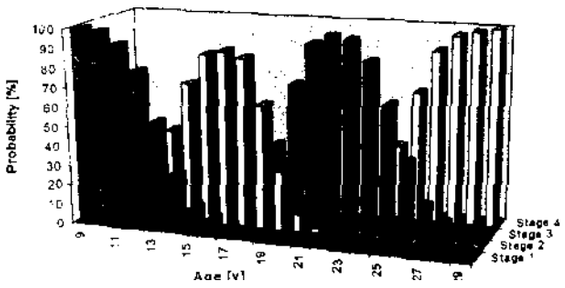
To set :Ill'ari/.0 experience Ei om our stud and that cii the literature. there scent Iti *N* no ShgI)I1JC:!J discre pancies in t lie esselitial parameters of the maturation procc ss oil hue mc dial clay ic cIa r epiphysis. This is a very umpuissant act, si nec the studies are from different eras of is cent U i\ anti the,k,forc reflect distinct nutritional ust onus and layin ~ intake of proteins and vitamins in cia ii[y] food, as well as the ingestion of hormones (e. g. c,r;il eontraeepii e usage). Furthermore, these data erc colLected from different ethnic groups and socioee ib m ic classes.



Figs. { i-l.ttiva of t.igc-rcI;iled uindairdized age distributions and V"IcIL-rencc jnicfliilS

Discussion

[nd a\ (Il ru is an ltic [casing demand torage estimations liv' lug Ind, duals The questions associated with these 1 c es' ma lit ins concern general criminal responsibility 'ge er 14 years) or the applicability of the adult orjuvenUe penal s stem (in Germany. age over 21 or under years) in juvenile delinquents. Often we have to examine young asv urn seekers without identification or sit h t a Se Ide ut it y papers who have been convicted of an ol Ic n c . s ual lv the are estimations are required to help in lii crentiat,ng between two or more possible aizes or birth dates I

Tb e p ri ii ei1la I methods available for age de te rmi na - aug u ec ts are those of radio logy, tooth morphtiltg. and hkichemistrv. These methods differ wide- 1 VL ft respect to potential. lim its and risks flu. 21 All sn2ullfieaibt ae determination methcs require ni CLI cal inl,l,enbon or examinations that are not usually mcdiea ll indicated. This poses a number of cluesit ins III I le21 and ethical nature that have to he ans C[C U in the specific sociopolitical situation. The most "I'lloilLiln are hethe r a physician may he in conflict itli the law in applying age determination meth- a ad n hiether these methods can legally he applied III list ng pcI soils without their consent. These questions riutist he decided in each individual case on the basis of the app rkip] IJ Ic regulations and the principles of mcdical cth,es. Detailed know ledge of the available mcth- OtIS and their potential and limits is of utmost impol'- allce 1191.

In the Federal Republic ot Germany. the application of rail; il ,w cal in ci hods for age identification in living (1 tIn U LI :I Is flutist he in accordance with the medical X-ra code I Rdnt e nv e rordn U ng. "ROy"). Generally, ra-

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segment of ihe appearance and iu.imI of the epiphpcs I' I. bones and the p"IC"' is LI ITCFC,iSi npUrtanca-

Hot cer- the process between ossification of an epiphy-
.'id 1[[11111 duaw'e normal Is Lams several Nears. This cmph:uvcx the importance of defining the exact stage it tie' ipnsnt for each epiphysis and of knowledge of th_ niripe of xariat!on lot the timine 01 union (26-281.

I|K 91cKern and Ste art study J7 showed that not ail epiphyses are of equal value in estimating age. Among the hest indicators were the epiphyses of the proxi nil humerus, distal radius, femoral head, iliac crest end media clavicle- Based on these findings, the tell rcnion. It age estimations in our department are the Ii :1 and r‘risl. the pelvis. and the medial end of IIio ct i idas. Thus, in addition to a.p. radiographs of II, li nd. wiii. and pelvis, tee routinely perform Cis of the ,erno iacicular joint when age estimations for IL' act !s in udo!escen cc or the third decade of life are required The aim of these age estimations is to detarmine fire most probable age of young delinquents ~tlthout amp identity papers who claim to have different birth dates during criminal procedures.

The following case may demonstrate the usefulness of bone age determination in such instances. A young u turn seeker from Albania was accused of rape. At carat AHees, he tf,pse different birth dates ranging be-P ccn Mauch I9i9 and November 19711. During the law-suil. he pr< tended to have been horn on II November so Ihat his age would have been 2Uvcars at that time As a consequence. lie would have been punished ace r in to the luvenle penal system. Bone age deter mina) r ii per loin cd using the above-mentioned test re-
lLm.. This shnaed I hot his skeletal maturation was nplctc IFig.61. According to Fio ■ the probability hi being t) Nears old with stage J of epiphyseal de-
ment if the medial clavicle was under 0.19 b. This -'suited in the adult penal system being applied in the I untie' criminal procedure.

(' mulnsiuns

l he c!evclopmcnt ofthe medial extremity of the clavicle Cain Cathie he assessed by computed tomography. In order to establish a reference population. we retrospec-

Fable 2. Survci &iI the Ilnict eoriii1rehcni\ 'AnILE le ne inth thi_ dc'eIOflnlL'flL a' he medial elavicular cptphv'iN

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Lively analyzed normal LieveIti1 iletit iII Im I i I'd isidual, under the age I ii U sears. The ossification of the medial clavicular epiplisis anLI LI' complete union with the clavicular shalt ntirma]\ lasts se'era ' ears. The data collected alhtns exact 'L 1tIi2 ol the de'. ciopilietit and provide the range ii \rrralLt,n lot the timing tifunioti. However, several Ijnittitttifls associated v,phi our icier ence populatititi remit',. The nuniber of inch' dualk IN limited, atid it retnaLns titicLeir IIIr greater sampLe size "ill Lead Its an increase ii the ice pe, tod of the tic- ye lopwe rita stages. I)ept Ic Ili, e pe r i ii cc available from the literature, the transtet of our data to other cliiow groups LiIi dilierent nLit]ttttmnal li[th:ts should be made with Cant In. Nes e rthe less. ht ne age dci e rm t nation based on lie studs of the cfevelopmettt ol the medial clavicular epiphvsis tniv !e a usentl adj(rnc, it) IkureI)-sic age identtfLe,Ition in lisinc inclnidttils. '('lit' method is also indicated for the idenhiticatttni tiE litrnniti remains whose mc is estimated at het'een I_c anl li ears.

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References

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Book review

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