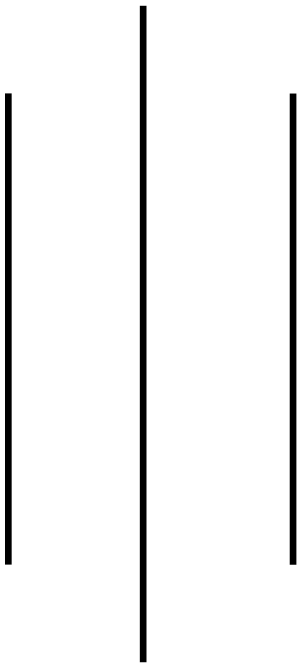
Reference Manual Of Forensic Age Estimation For Living Individuals in Nepal



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The goal of the guideline

In the absence of any protocol for age estimation, there has been a lack of uniformity in the age estimation procedure in Nepal. The fact that forensic medicine experts are not the only personnel coordinating and performing age estimation and the procedure has been also performed by medical officers and physicians of any specialties, formulation of the standard operating protocol can be helpful to perform age estimation more scientifically and uniformly throughout the nation.

It has been recognized that age estimation needs multidisciplinary coordination for the success of the exam. The protocol also includes the responses of other professionals, as they relate to the examination process.

The objective of age estimation

The objective of age estimation is to estimate the chronological age or range of age of persons of unknown or disputed age opting for the most accurate procedure.

Need of age estimation

In the developing countries, many births are not registered. The unavailability of the birth certificates creates the situation of official invisibility and they will be devoid of their rights. This also creates a problem of their legal age when the need arises. With the unavailability of valid documents ascertaining their age, children may be vulnerable to recruitment into the armed forces, and domestic and industrial works. It also creates a problem of ascertaining the criminal responsibility of those involved. The unavailability of birth registration and legally valid identity cards revealing the age of the person may lead to greater chances of abuse of the system by law enforcement officials, plaintiffs, and defendants either processing children as adults or adults as children.

Forensic age estimation is one of the expertise of forensic medicine which delves to define the chronological age of persons of unknown age opting for the most accurate procedure. The use of the term “estimation” rather than “diagnosis” reflects the real limits of this procedure. The courts of law and at times other public institutions require expert reports of the age of individuals. There is no medical test or a group of tests that exactly ascertains the age of the given individual. Although, in routine practice, physicians estimate the age of individuals based on physical development, radiological examination of bones, and dental examination findings. When in doubt, the benefit of the doubt should go to the individual whose age is being assessed. The opinion of the experts on the age of the individual is taken into consideration by the judiciary and other public institutions.

Forensic Age Estimation (FAE) is not a recent field in terms of the practice of Forensic Sciences and Law. In the old Roman Empire, the consideration of entry of a young male into military service was determined by the eruption of the permanent second molar. In ancient times, age estimation was mainly based on dental examination. With the use of X-rays in the medical field, it also gained importance in age estimation and the radiographs of the skeleton were used as a complement to the conventional dental age estimation methods. In the modern time, there are different methods of age estimation in use. Many of them are backed up by scientific evidence.

Medico legal importance of age includes but is not limited to:

a) Establishment of the age of majority
b) Right to vote
c) Age of marriage
d) Consent to sexual relationship and rape
e) Age of criminal responsibility
f) Driving license
g) Age of valid consent
h) Participation in competitive games
i) Employment
j) Recruitment in public posts

Establishment of the age of majority

a. National Civil Code 2074 (2017) defines children as persons who have not completed the age of 18 years.
b. Nepal Citizenship Act 2063 (2006) defines "minor" as a person who has not attained the age of 16 years. A person attaining the age of 16 years is a major and can get citizenship by fulfilling the legal requirements. Once a person becomes a major, he can enjoy various civil rights.
c. Human Trafficking and Transportation (Control) Act, 2064 defines “Child” as a person who has not reached the age of 18 years.
d. The Act Relating to Children, 2075 (2018) defines "Children" as persons who have not completed the age of 18 years.

Right to vote

Each citizen of Nepal who has completed the age of 18 years shall have the right to vote in any one election constituency as provided for in the Federal law, for Federal Legislature, State Assembly, Village and Municipal Assembly according to the constitution of Nepal 2072.

Age of marriage

Age of Marriage: The age of marriage is 20 years for both males and females. (No 173 of The National Penal (Code) Act, 2017 (2074).

Consent to sexual relationship and rape

National Penal Code “On Sexual offence” has explained the consent of sexual relationship and rape as follows:

219, Number 1. If a person enters into sexual intercourse with a woman without her consent or enters into sexual intercourse with a girl below the age of 18 years with or without her consent shall be deemed to be an offence of rape.

219, Number 3. A person who commits rape shall be liable to the imprisonment as mentioned hereunder:

a. Imprisonment for a term ranging from 16 years to 20 years if the minor girl is below the age of 10 years
b. Imprisonment for a term ranging from 14 years to 16 years if the minor girl is above 10 or more years of age but below 14 years of age.
c. Imprisonment for a term ranging from 12 years to 14 years if the minor girl is of 14 years of age or above but below 16 years of age.
d. Imprisonment for a term ranging from 10 years to 12 years if the woman is of 16 years of age or above but below 18 years of age.

e. Imprisonment for a term ranging from seven years to 10 years if the woman is of 18 years of age or above.

Indecency and immoral acts

According to the National Penal Code, 2074 (No 122), a person of age 10 years and above should not expose his or her genitals or perform any sexual activities in public except that required for medical or treatment purposes.

Age of valid consent

a. No 20 of the National Penal Code has made a provision for providing valid consent from persons above 18 years.
b. A person above 18 years can give valid consent to suffer any harm, which may result from an act, which is not intended or known to cause death or grievous hurt. (National Criminal Code no 15)
c. As mentioned in The Human Body Organ Transplantation (Regulation and Prohibition) Act, 2055 (1998), organs can be extracted from the body of an alive person when the donor gives consent voluntarily to donate the organ and has completed the age of 18 years.

Age of criminal responsibility

Criminal Responsibility (No 45 of National Penal Code of Nepal 2074)

a. If a child below 10 years commits any act, it is not considered an offence. (Criminal procedure code 2074, No 45)
b. No punishment is awarded to the person if, at the time of committing the crime, the age is less than 10 years. (National Criminal procedure code 2074, No 45-1)
c. If the age is 10 to 14 years, if imprisonment is to be done, it should be for a maximum of six months or kept at reform homes for up to one year only. (National Criminal procedure code, 2074 No 45 (2)).
d. For a child of age 14 to 16 years, the punishment will be half as of the adults and for a child aged 16 to 18 years, it will be two-thirds that of adults. (National Criminal procedure code 2074 No 45 2 and 3).
e. If a child commits an offence under the advice or influence of any person, the person doing such an act shall be liable for full punishment as per the law as if he/she has committed such an offence. (National Criminal Code No. 28)

Provisions related to criminal liability and age from the Act Relating to Children, 2075 (2018) (Children Act 2075)

Section 36: Provisions relating to punishment

a. Sec 36(1) If the child is less than ten years of age at the time of the commission of the offence, no case and punishment of any kind shall be instituted against and imposed on him or her.
b. Sec.36 (2) If a child of ten years of age or above but below fourteen years of age commits an offence that is punishable by a fine, the child shall be released after counselling him or her and if such a child commits an offence that is punishable by imprisonment, the child shall be punished with imprisonment for up to six months or be sent to the child reform home for a period not exceeding one year without subjecting him or her to imprisonment.
c. Sec36 (3) If a child of fourteen years of age or above but below sixteen years of age commits an offence, the child shall be punished with half the punishment that is imposable on the person having attained majority pursuant to the prevailing law.

d. Sec36 (4) If a child of sixteen years of age or above but below eighteen years of age commits an offence, the child shall be punished with two-thirds of the punishment that is imposable on the person of legal age pursuant to the prevailing law.
e. Sec.36 (5) The Juvenile Court shall, having regard, inter alia, to the age, sex,and maturity of the child who is held to be subject to punishment pursuant to subsection (2), (3) or (4), nature of the offence and also the circumstances of the commission of the offence, postpone his or her punishment or make any of following appropriate decisions as punishment, with or without specifying the terms and conditions:
    (a) To counsel or advise the child about good human behaviours by any family member or guardian,
    (b) To give orientation to the child through any institution or person that provides the service,
    (c) To provide single, group or family psycho-social counselling services,
    (d) To keep the child under the observation of any family member, guardian, school, person or institution that provides service for a fixed period subject to the observance of the specified terms and conditions,
    (e) To send the child for community service that is suitable to his or her age, by specifying the nature and period of service,
    (f) To make the child stay in the child reform home for a period not exceeding that of the punishment imposed on him or her.
f. Sec.36 (6) If any person has caused a child to commit an offence, by teaching, giving pressure, ordering, luring or in any other manner, that person who has taught so, given pressure, ordered, lured or made to commit it shall be punished pursuant to law as if that person committed the offence on his or her own.
g. Sec. 36 (7) Notwithstanding anything contained elsewhere in this Section, while punishing a child who has not completed sixteen years of age, no punishment of imprisonment shall be imposed on such a child except in cases where he or she has committed a heinous offence, grave offence or repeated the offence.

Driving License

According to Motor Vehicles and Transport Management Act, 2049 (1993), A person attaining the age of 21 years is eligible to get driving license for a heavy motor vehicle, 18 years of a medium and light motor vehicle, and 16 years for a motorcycle and similar another two-wheel motor vehicle

Prohibition on Engaging a Child in Works

As per the provision of the Child Labor (Prohibition and Regulation) Act, 2056 (2000), no child having not attained the age of 14 years shall be engaged in work as a laborer.

Some age-related civil issues (National Civil code of Nepal)

a. 10 years: Can give choose parents during divorce
b. 14 years: Maximum age of adoption
c. 21 years: Can stay separate from parents without consent.

Provision of punishment according to the gestational age of the fetus

Section 188 of the National Penal Code of Nepal 2074 mentions criminal abortion. The punishment for the offense differs according to the gestational age of the fetus which is as follows: [Sec 188 (3)]

a. If the gestational period is up to 12 weeks, the punishment shall be up to one-year imprisonment and up to Rs. 10000/- fine

b. If the gestational period is up to 25 weeks, the punishment shall be up to three years imprisonment and up to Rs. 30000/- fine
c. If the gestational period is above 25 weeks, the punishment shall be up to five years imprisonment and up to Rs. 50000/ fine

Requisition and need for age assessment

No. 80 of the Act Relating to Children, 2075 (2018) mentions the basis for determining children's age. The date of birth recorded in the child's birth registration issued by the hospital is the basis for determining the age of the children. If that is not available, the date of birth recorded in the child's birth registration certificate issued by the Local Registrar's Office is considered. In case that is also not possible, the date of birth recorded in the child's school character certificate, or the date of birth recorded at the time of the child's admission to the school is the basis. The age recorded in the *Janmakundali* (birth chart), *Cheena* (horoscope), notes, or the age disclosed by the father, mother, guardian, or any other family member of the child or similar other relevant evidence may also be the basis of ascertaining the age of the child.

The medical personnel can be requested to perform age estimation from the courts or any public institution. Whenever there is the unavailability of valid certificates disclosing the age of the person and/or the age is contested, the expert may be referred for age estimation.

Child Labor (Prohibition and Regulation) Act, 2056 (2000) Number 12 mentions the disputes relating to age: (1) In case of a dispute relating to the age of a child engaged in an enterprise, his/her age as per the date of birth referred to in the birth registration certificate shall be deemed to be his real age. (2) If any child is not having the birth registration certificate, the date determined upon examination by a medical practitioner shall be deemed to be his/her actual age.

Evidence Act 2031, No 23. mentions that the personal opinion of experts can be taken as evidence.

Competency required and consultations

It is important that age assessment should be performed by qualified personnel with the required skill and capacity of logical interpretation. This is important both ethically and legally as the reports are made in the interests of justice. The resulting estimation must be able to withstand legal challenges. It should also be considered that the erroneous results have huge humanitarian implications. In order to overcome this, the personnel who are trained specializing in Forensic Medicine and/or allied disciplines like Forensic Anthropology, and Forensic Odontology should be involved in this sensitive job. The personnel involved should receive appropriate initial and ongoing training. In this area, a collaborative knowledge of very diverse disciplines like Forensic and Physical Anthropology, Odontology, Radiology, etc. is needed.

Comprehensive report to be provided by a coordinator

The physician who takes the responsibility of age estimation can act as a coordinator and take the help of professionals of other disciplines like qualified dentists, radiologists, anthropologists, etc. He has to compile the reports or opinions provided by those professionals, but he has to prepare the final comprehensive reports.

Consent before commencing the procedure

The examinee should understand the full nature of their consent to the procedure. This can be accomplished by presenting them with all the relevant information in a language they can easily

understand. Informed consent should be taken from the individual and/or the representative prior to undergoing age estimation. It is necessary as medical age assessment is an invasion of privacy without therapeutic benefit to the individual. As well the individual has to be exposed to X-rays. The procedure, outcome, and consequences of the procedure should be explained to the patient in a comprehensive manner, in a simple language that they can understand. (minors/ language barriers) It is the right of the patients to decline any part or all of the examination. However, the informed consent process should also include making patients aware of the impact of declining a procedure. They should understand that declining a procedure might also be used by opposing counsel to discredit them at trial.

Recording of identification marks

The examiner should record two identification marks from the examinee. The marks should be on the exposed parts of the body and not on hidden parts, so the examinee won't be embarrassed in court where these marks are validated.

Selection of methods for age estimation

Though there are many published papers on age estimation and several methods developed, the appropriate one should be chosen considering the specific conditions of each case.
The age diagnosis examination should include:

1. A physical examination that also records anthropometric data, signs of sexual maturation, and any age-relevant developmental disorder.
2. An X-ray examination of the left hand.
3. A dental examination that records dentition status and evaluates an X-ray examination of the dentition.
4. If the skeletal development of the hand is completed, an additional examination of the clavicles should be carried out, preferably by means of a conventional X-ray examination and/or a CT scan.

It is also recommended that these methods should be used in combination in order to increase accuracy in age estimation as well as the identification of age-associated developmental disorders. Each portion of the examination should be preferably performed by a specialist with experience in preparing expert reports. The coordinating expert should provide a comprehensive assessment on the basis of the different portions of the evaluation performed by the respective specialists.

In accordance with the guidelines proposed by Ritz-Timme et al for an age assessment method to be considered acceptable, it must fulfill the following requirements:

1. The method must be transparent and provable, presented to the scientific community, as a rule by publication in peer-reviewed journals.
2. Clear information concerning accuracy of age assessment by the method should be available.
3. The method needs to be sufficiently accurate to fulfil the specific demands of the single case to solve the underlying questions.
4. In cases of age assessment in living individuals principles of medical ethics and legal regulations have to be considered, especially if medical intervention is involved.

Reference material used must fulfill certain requirements (Solari & Abramovitch, 2002):

- Adequate sample size. The number of subjects of each sex and age group should be ten times the number of the examined features.
- The age indicated by the subjects should be verified.

- An even distribution of subjects across all age groups.
- All data have to be collected separately for both sexes.
- The time of the examination should be recorded.
- The examined features should be defined unambiguously.
- The technique used in the examination should be described precisely.
- Information on genetic-geographic origin, socio-economic status, and health of the reference population is indispensable.
- The sample size, mean value, and statistical parameters of deviation should be provided for every feature examined.
- Information on inter- and intra-observer error is desirable.

The age estimation methods should also be tested to the Nepalese population and population-specific formula and predictions derived.

Note: In case of unavailability of population-based studies fulfilling the criteria as described above, age determination can be done using multiple parameters like physical examination, dental examination, radiographs, radiographs of several bones depending on the suspected age group, and miscellaneous particulars.

Physical examination

The physical examination includes measurements such as body height and weight, body type, and body mass index along with signs of sexual maturity. If there are any signs suggestive of a pathological condition that can interfere with the maturation of the person. The anthropometric assessments are highly variable and do not provide a conclusive estimation of age.

A full-term child at birth is, on average, 50 cm in length measured from crown to heel, and 2.5 to 3 Kg in weight. It is generally 60 cm in length in the sixth month and 68 cm at the end of the first year. At the end of the fourth year, it is, on average, double its length at birth. The weight of the child increases nearly by 0.453592 Kg (one pound) a month during the first year. The birth weight gets doubled at the end of the fifth month and tripled at the end of the first year. The progressive increment in height and weight is variable and cannot be the sole factor in the determination of age from medico-legal point of view.

Secondary sexual characters

- The growth of hair appears first on the pubis and then in the axillae. In the adolescent stage, the development of the pubic hair in both the sexes follows the following stages:
- One of the first signs of the beginning of puberty is chiefly on the base of the penis or along labia, where there are few long slightly pigmented and curled or straight downy hair.
    - The hair is coarser, darker and more curled, and spread sparely over the junction of pubis
    - More or less like an adult, but only a smaller area is covered, no hair on the medial surface of thighs
    - Adult type with the spread of hair of the horizontal (or classically "feminine') pattern, also on the medial surface of the thighs. In the case of girls, it commences with the appearance of soft and pale colored downy hair on the pubis at the age of about 13 years, and a few sparse dark hairs appears at about 14 years.

    - The growth becomes thicker in the course of a year or two, when hair commences to grow in the axilla.
- In boys, downy hair appears on the pubis at about 14 years, and a few dark hairs appear at about 15, when downy hair begins to grow in the axillae. A thick growth of dark hair is well marked on the pubis, scrotum and in the axillae at about 16 or 17 years of age.
- Hair begins to appear on the chin and the upper lip between 16 and 18 years.
- Boys develop a deep voice between 16 and 18 years when pomum adami becomes more prominent.

The most commonly used method for the study of secondary sexual characteristics is the staging advised by Tanner (Marshall & Tanner, 1969, 1970). It uses a five-stage scale to evaluate the status of pubic hair growth and breast development in girls, and pubic hair growth and development of the penis, scrotum and testes in boys.

Breast development stages (girls) (Marshal & Tanner, 1969)
Stage 1: Prepubertal, papilla elevation only.
Stage 2: Breast bud stage, elevation of breast and papilla as a small mound, enlargement of areola diameter.
Stage 3: General enlargement of breast and areola.
Stage 4: Projection of areola and papilla as secondary mound.
Stage 5: Mature stage, adult contour with areola in same contour as breast and only papilla projecting.

Pubic hair growth stages (girls) (Marshal & Tanner, 1969)
Stage 1: Prepubertal, no pubic hair.
Stage 2: Sparse growth of long, slightly pigmented, downy hair, straight or only slightly curled, chiefly along the labia.
Stage 3: Considerably darker, coarser and more curled, with an increase in amount. The hair spreads sparsely over the junction of the pubes.
Stage 4: Hair resembles adult type, but no spread to the medial surface of the thighs.
Stage 5: Adult in quantity and type, spread to medial thighs.

Genital development stages (boys) (Marshal & Tanner, 1970)
Stage 1: Prepubertal, no change in size or proportion of testes, scrotum and penis from early childhood.
Stage 2: Enlargement of scrotum and testes, reddening and change in the texture of the scrotal skin.
Stage 3: Increase first in length then breadth of penis, further growth of testes and scrotum.
Stage 4: Enlargement in length and breadth of penis and development of glans, further growth of testes and scrotum, darkening of the scrotal skin.
Stage 5: Genitalia adult in size and shape.

Pubic hair stages (boys) (Marshal & Tanner, 1970)
Stage 1: Prepubertal, no pubic hair.
Stage 2: Sparse growth of long, slightly pigmented, downy hair, straight or slightly curled, chiefly at the base of the penis.
Stage 3: Considerably darker, coarser and more curled, with an increase in amount. The hair spreads sparsely over the junction of the pubes.
Stage 4: Hair resembles adult type, but no spread to the medial surface of the thighs.
Stage 5: Adult in quantity and type, spread to medial thighs.

Other age changes appearing on the body

- **Greying of hair:** Hair on the head tends to become grey usually after 40 years and silvery white in advanced old age. Hair may be greyed earlier because of hereditary peculiarity, grief, shock, trophic changes produced by neuralgia or other diseases affecting the fifth nerve.
- **Arcus senilis:** Atheromatous arteries, and an opaque zone in the cornea, known as arcus senilis, are rarely seen before the age of 40 years.
- **Wrinkles on the face:** Begin to appear at 40 years.

No reliance can be placed on these signs though. Evaluation of age on the basis of physical examination and sexual development is not reliable and therefore it should be done in association with other methods. But physical examination findings are very important for evaluating the potential impact of various pathological conditions on the status of maturation derived by other methods. Most of the diseases delay development and thus can lead to underestimation of age. This won't disadvantage the person concerned with the judicial issues. On the contrary, overestimation of age in persons affected by some diseases affected by developmental disorders should be avoided at all costs. Certain endocrinal diseases though rare may affect the early attainment of height and sexual development as well the skeletal development. Endocrine diseases that may accelerate skeletal development include precocious puberty, adrenogenital syndrome, and hyperthyroidism. The general physical examination may reveal symptoms such as exophthalmos, virilization of girls, acromegaly, and gigantism, which are indicative of pathological disorders. These findings can help the examiner to redirect the estimation of age. The possible endocrine disorder should be thought of when there is a discrepancy between skeletal age and dental age. Dental development usually remains unaffected by endocrine disorders.

Teeth

Tooth Development and eruption

The alveolar cavities containing teeth are formed around the third or fourth month of intrauterine life. Development of the tooth begins with the formation of cellular tooth germ within the alveolar bone, in the shape of the crown. Apposition and calcification of enamel and dentin take place within this germ, and the crown is completely formed and calcified before any positional changes occur. At birth, the rudiments of all the temporary teeth and of the first permanent molars may be found in the jaws.

Root formation begins after the completion of the crown and as the root becomes longer, the crown erupts through the bone and finally comes out of the jaws. The root is completed sometime after the tooth is in full functional occlusion. The teeth calcify from the crown to the neck to the roots. During the eruption of a permanent tooth, the overlying root of its deciduous predecessor simultaneously undergoes absorption until only the crown remains. The unsupported crown then falls off.

Types of teeth:

There are two sets of teeth in a human. They are temporary (primary) teeth and permanent teeth. (table 1)

Temporary teeth

Temporary, deciduous, or milk teeth; are synonymously used terms. They are 20 in number: four incisors, two canines, and four molars in each jaw. When teeth are divided into quadrants, there is one central incisor, one lateral incisor, one canine, and two molars in each quadrant.

Permanent teeth

There are 32 permanent teeth. They are four incisors, two canines, four premolars, and six molars in each jaw. Then teeth are divided into quadrants, there are one central incisor, one lateral incisor, one canine, two premolars, and three molars in each quadrant.

Superadded permanent teeth: Those which do not have deciduous predecessors. They erupt posterior to the primary teeth. All the permanent molars (six in each jaw) are superadded permanent teeth.

Successional permanent teeth: Those teeth which erupt in place of deciduous teeth. Premolars erupt in the place of deciduous molars. There are ten successional teeth in each jaw. (KSN Reddy)

Table 1: Differences in morphology of primary and permanent teeth:

SN	Features	Primary teeth	Permanent teeth
	Crown		
1	Enamel	Thinner (About 1 mm)	Thicker (About 2-3 mm)
2	Occlusal plane	Relatively flat	More curved contour
	Occlusal table	Narrow	Broad
3	Mammeleons	Absent	Present
	Cervical constrictions	Marked	Less marked
	Pulp		
4	Pulp chamber	Larger, closer to surface	Smaller, significant gap from the surface
5	Root canals	More ribbon like (Hour glass appearance)	Well defined with less branching
6	Accessory canals	Present	May be absent
	Root		
7	Shape	Larger and more slender	Shorter and bulbous
8	Root trunk	Smaller	Larger
9	Width	Narrower mesiodistally	Broader mesiodistally
10	Physiological resorption	During shedding of teeth	Absent

Table 2: FDI notation of permanent and deciduous teeth

Permanent teeth															
Patient's upper right								**Patient's upper left**							
18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Patient's lower right								**Patient's lower left**							
Deciduous teeth															
Upper right								**Upper left**							
			55	54	53	52	51	61	62	63	64	65			
			85	84	83	82	81	71	72	73	74	75			
Lower right								**Lower left**							

FDI (Federation Dentaire Internationale) notation

FDI World Dental Federation notation is widely used by dentists internationally to associate information to a specific tooth. Orientation of the chart is traditionally "dentist's" view", i.e. patient's right corresponds to notation chart left. The designations "left" and "right" on the chart below correspond to the patient's left and right. (table 2)

Table 3a: Quadrant code for permanent teeth	
1	Right Upper Quadrant
2	Left Upper Quadrant
3	Left Lower Quadrant
4	Right Lower Quadrant

Table 3b: Quadrant code for primary/decidious teeth	
5	Right Upper Quadrant
6	Left Upper Quadrant
7	Left Lower Quadrant
8	Right Lower Quadrant

Table 4a: Tooth Code for permanent teeth	
1	Central Incisor
2	Lateral Incisor
3	Canine
4	First Premolar
5	Second Premolar
6	First Molar
7	Second Molar
8	Third Molar

Table 4b: Tooth Code for primary/decidious teeth	
1	Central Incisor
2	Lateral Incisor
3	Canine
4	First Molar
5	Second Molar

Table 5a: FDI notation system for permanent teeth in first quadrant (Clockwise):	
Notation	**Tooth**
18	Maxillary right Third molar
17	Maxillary right second molar
16	Maxillary right first molar
15	Maxillary right second premolar
14	Maxillary right first premolar
13	Maxillary right canine
12	Maxillary right lateral incisor
11	Maxillary right central incisor

Table 5b: FDI notation system for permanent teeth in second quadrant (Clockwise):	
Notation	**Tooth**
21	Maxillary left central incisor
22	Maxillary left lateral incisor
23	Maxillary left canine
24	Maxillary left first premolar
25	Maxillary left second premolar
26	Maxillary left first molar
27	Maxillary left second molar
28	Maxillary left third molar

Table 5c: FDI notation system for permanent teeth in third quadrant (Clockwise):	
Notation	**Tooth**
38	Mandibular left third molar
37	Mandibular left second molar
36	Mandibular left first molar
35	Mandibular left second premolar
34	Mandibular left first premolar
33	Mandibular left canine
32	Mandibular left lateral incisor
31	Mandibular left central incisor

Table 5d: FDI notation system for permanent teeth in fourth quadrant (Clockwise):	
Notation	**Tooth**
41	Mandibular right central incisor
42	Mandibular right lateral incisor
43	Mandibular right canine
44	Mandibular right first premolar
45	Mandibular right second premolar
46	Mandibular right first molar
47	Mandibular right second molar
48	Mandibular right third molar

Table 5e: FDI notation system for primary teeth in first quadrant (Clockwise):	
Notation	**Tooth**
55	Maxillary right second molar
54	Maxillary right first molar
53	Maxillary right canine
52	Maxillary right lateral incisor
51	Maxillary right central incisor

Table 5f: FDI notation system for primary teeth in second quadrant (Clockwise):	
Notation	**Tooth**
61	Maxillary left central incisor
62	Maxillary left lateral incisor
63	Maxillary left canine
64	Maxillary left first molar
65	Maxillary left second molar

Table 5g: FDI notation system for primary teeth in third quadrant (Clockwise):	
Notation	**Tooth**
75	Mandibular left second molar
74	Mandibular left first molar
73	Mandibular left canine
72	Mandibular left lateral incisor
71	Mandibular left central incisor

Table 5h: FDI notation system for primary teeth in fourth quadrant (Clockwise):	
Notation	**Tooth**
81	Mandibular right central incisor
82	Mandibular right lateral incisor
83	Mandibular right canine
84	Mandibular right first molar
85	Mandibular right second molar

Dental age

Many of the teeth are simultaneously developing in childhood and hence dental examination is very helpful during childhood.

Teeth are useful for age determination by:

a. Eruption
b. Stage of development
c. Secondary changes.

Age estimation of age from the teeth by noting the number of teeth erupted; location and stage of eruption and with X-ray examination with some amount of certainty is possible up to 17 to 20 years of age.

Eruption of teeth

The eruption is defined as the superior part of the crown of the tooth appearing level with the surface of the alveolar bone. In both deciduous and permanent dentition, an eruption occurs earlier in the lower jaw except for the lateral incisors which erupt earlier in the upper jaw.

The number and eruption of deciduous teeth are more regular than the of permanent dentition. The eruption is not always bilaterally symmetrical. Tooth eruption in females may be one year before that of males.

This method is convenient, time-saving, cheap, and not much influenced by intra and inter-observer error. Although eruption is not a reliable indicator of age when used alone, due to factors like inter-individual or population variation, systemic or local diseases, or the elapsed time without changes.

The ethnic, cultural, hereditary, environmental, endocrine reactions, and nutrition all play a part in eruption and calcification of teeth. Eruption tends to occur earlier in warmer climates and in urban areas.

Table 6a: Calcification, eruption, root completion and root resorption of deciduous teeth				
Teeth	Beginning of calcification (Months IU)	Eruption (Months)	Completion of calcification of root (Years)	Beginning of resorption of root
Central Incisors				
Lower	5-6	6-8 months	1.5 -2	4th year
Upper	5-6	7-9 month	1.5 -2	5th year
Lateral Incisors				
Lower	5-6	10-12 month	1.5 -2	5th year
Upper	5-6	7-9 month	1.5 -2	5th year
Canines	5-6	17-18 month	2.5-3	8th year
First molars	5-6	12-14 month	2-2.5	6th year
Second molars	5-6	20-30 month	3	7th year

Table 6b: Calcification, eruption and root completion of permanent teeth			
Tooth	**Beginning of calcification**	**Eruption (years)**	**Completion of root (years)**
First molar	At birth	6-7	9-10
Central Incisor	3-4 months	6-8	10
Lateral incisor	1 year	7-9	11
First premolar	1.5 years	9-11	12-13
Second premolar	2 years	10-12	12-14
Canine	4-5 months	11-12	12-13
Second molar	2.5-3 years	12-14	14-16
Third molar	8-10 years	17-25	18-25

A study was conducted among school children of Dhulikhel district of Nepal including 450 healthy populations between the ages of six months and 25 years. The samples were taken from students of different schools around Dhulikhel, KUSMS student and patients coming to Outpatient Department of Dhulikhel Hospital, Kathmandu University Hospital. Karki R has presented the age eruption of primary and permanent teeth which is presented in the tables.

Table 7a: Age of eruption of temporary tooth in Nepalese (Karki R)				
S.No.	**Teeth**	**Upper/ Lower jaw**	**Range of age at which tooth erupts (Months)**	**Mean ± SD**
1	Central Incisor	Lower	06.7-09.8	07.92 ± 1.30
		Upper	08.2-11.0	09.83 ± 0.96
2		Upper	08.2-13.6	10.96 ± 0.86

	Lateral Incisor	Lower	08.8-14.9	12.52 ± 1.51
3	First Molar	Lower	12.9-16.5	13.94 ± 1.01
		Upper	14.3-16.2	15.83 ± 0.84
4	Canines	Upper	19.1-23.6	21.32 ± 1.43
		Lower	19.5-24.0	21.80 ± 1.46
5	Second Molar	Upper	24.6-31.1	28.54 ± 3.24
		Lower	24.3-31.6	28.57 ± 3.21

Table 7b: Age of eruption of permanent teeth in Nepalese (Karki R)

S.No.	Teeth	Upper/ Lower jaw	Range of age at which tooth erupts (Years)	Mean ± SD
1	First Molar	Lower	05.9-07.8	06.60 ± 0.52
		Upper	05.9-07.6	06.01 ± 0.51
2	Central Incisor	Lower	06.4-08.6	07.32 ± 0.64
		Upper	06.7-08.9	07.89 ± 0.72
3	Lateral Incisor	Lower	07.6-09.8	08.92 ± 0.56
		Upper	07.6-09.8	08.92 ± 0.56
4	First Pre-molar	Upper	09.3-11.3	10.16 ± 0.44
		Lower	09.5-11.4	10.13 ± 0.43
5	Second Premolar	Upper	10.1-11.3	10.69 ± 0.39
		Lower	10.2-11.6	10.71 ± 0.40
6	Canine	Upper	10.5-12.9	11.05 ± 0.91
		Lower	10.7-13.0	11.18 ± 1.02
7	Second Molar	Lower	11.9-14.4	13.12 ± 1.14
		Upper	12.0-14.7	13.14 ± 1.20
8	Third Molar	Upper	18.6-24.8	21.92 ± 2.35
		Lower	18.9-24.9	21.98 ± 2.37

The complete closure of the roots of the teeth occurs after two to three years after eruption of the teeth.

A study was carried out in 623 Nepalese school children in Dhulikhel district with age ranging from 5 to 14 years. Physically and mentally healthy children with age ranging from 5 to 14 years were included in the study. Children with a history of chronic infectious disease, nutritional, or endocrine disturbances, recognized syndromes and developmental disturbances such as cleft lip and palates were excluded. (Upadhyay S et al 2016)

The time of eruption of permanent teeth is presented in the tables:

Table 8a: Number and percentage of permanent maxillary teeth emerged at different ages in Nepalese (Upadhyay S et al)

Age in years	Sex	Central Incisor	Lateral Incisor	Canine	First Premolar	Second Premolar	First Molar	Second Molar
5	Boys	0	0	0	0	0	0	0
	Girls	0	0	0	0	0	0	0
6	Boys	0	0	0	0	0	11(42.3%)	0
	Girls	0	0	0	0	0	13(54.2%)	0
7	Boys	1(3.2%)	0	0	0	0	28(90.3%)	0
	Girls	4(14.3%)	0	0	0	0	26(92.9%)	0
8	Boys	27(75.0%)	8(22.2%)	0	0	0	36(100%)	0
	Girls	16(61.5%)	5(19.2%)	0	0	0	26(100%)	0
9	Boys	35(92.1%)	19(50%)	0	3(7.9%)	0	38(100%)	0
	Girls	28(96.6%)	16(55.2%)	0	2(6.9%)	0	29(100%)	0
10	Boys	49(100%)	41(83.7%)	3(6.1%)	4(8.2%)	1(2.0%)	49(100%)	0
	Girls	46(100%)	44(95.7%)	3(6.1%)	14(30.4%)	2(4.3%)	46(100%)	0
11	Boys	41(100%)	41(100%)	9(22.0%)	19(46.3%)	7(17.1%)	41(100%)	4(9.8%)
	Girls	53(100%)	53(100%)	28(52.8%)	33(62.3%)	18(34.0%)	53(100%)	14(26.4%)
12	Boys	42(100%)	42(100%)	29(69.0%)	41(97.6%)	30(71.4%)	42(100%)	15(35.7%)
	Girls	50(100%)	50(100%)	43(86.0%)	47(94.0%)	36(72.0%)	50(100%)	31(62.0%)
13	Boys	20(100%)	20(100%)	20(100%)	20(100%)	17(85.0%)	20(100%)	17(85.0%)
	Girls	22(100%)	22(100%)	22(100%)	22(100%)	22(100%)	22(100%)	21(95.5%)
14	Boys	21(100%)	21(100%)	21(100%)	21(100%)	21(100%)	21(100%)	21(100%)
	Girls	19(100%)	19(100%)	19(100%)	19(100%)	19(100%)	19(100%)	19(100%)

Table 8b: Number and percentage of permanent mandibular teeth emerged at different ages in Nepalese (Upadhyay S et al)								
Age in years	**Sex**	**Central Incisor**	**Lateral Incisor**	**Canine**	**First Premolar**	**Second Premolar**	**First Molar**	**Second Molar**
5	Boys	0	0	0	0	0	0	0
	Girls	0	0	0	0	0	0	0
6	Boys	2(7.7%)	0	0	0	0	12(46.2%)	0
	Girls	7(29.2%)	0	0	0	0	19(79.2%)	0
7	Boys	21(67.7%)	3(9.7%)	0	0	0	28(90.3%)	0
	Girls	19(67.9%)	3(10.7%)	0	0	0	27(96.4%)	0
8	Boys	36(100%)	19(52.8%)	0	0	0	36(100%)	0
	Girls	26(100%)	16(61.5%)	0	0	0	26(100%)	0
9	Boys	38(100%)	34(89.5%)	2(5.3%)	0	0	38(100%)	0
	Girls	29(100%)	26(89.7%)	3(10.3%)	1(3.4%)	0	29(100%)	0
10	Boys	49(100%)	49(100%)	9(18.4%)	3(6.1%)	0	49(100%)	0
	Girls	46(100%)	46(100%)	18(39.1%)	14(30.4%)	3(6.5%)	46(100%)	0
11	Boys	41(100%)	41(100%)	20(48.8%)	19(46.3%)	9(22.0%)	41(100%)	6(14.6%)
	Girls	53(100%)	53(100%)	38(71.7%)	33(62.3%)	22(41.5%)	53(100%)	21(39.6%)
12	Boys	42(100%)	42(100%)	34(81.0%)	35(83.3%)	23(54.8%)	42(100%)	19(45.2%)
	Girls	50(100%)	50(100%)	47(94.0%)	48(96.0%)	37(74.0%)	50(100%)	41(82.0%)
13	Boys	20(100%)	20(100%)	20(100%)	20(100%)	20(100%)	20(100%)	17(85.0%)
	Girls	22(100%)	22(100%)	22(100%)	22(100%)	22(100%)	22(100%)	21(95.5%)
14	Boys	21(100%)	21(100%)	21(100%)	21(100%)	21(100%)	21(100%)	21(100%)
	Girls	19(100%)	19(100%)	19(100%)	19(100%)	19(100%)	19(100%)	19(100%)

From the study, the sequence of emergence of maxillary teeth were first molar, central incisor, lateral incisor, first premolar, canine, second premolar and second molar whereas for mandible it was first molar, central incisor, lateral incisor, canine, first premolar, second premolar and second molar.

Dental maturation

The deciduous tooth crowns start to be mineralized at around 3 or 4 months of intrauterine life. The calcification continues after birth during the neonatal period. The formation of roots is generally completed from 18 months to 3 years of age. The mineralization of permanent teeth takes about nine years starting with the first permanent molar around the time of birth.

The dental development process can be categorized on the basis of different morphological stages of mineralization which can be studied with radiographic techniques. The development is more uniform and presents gradual changes than an eruption. It is more controlled by genetics and less influenced by external factors than all other measurable criteria of maturity.

The assessment of dental development consists of evaluating the teeth by radiographs; intraoral periapical (IOPA) or orthopantomogram (OPG) and the stage of development is related to the age of teeth development based on the studies on known age.

One of the systems most universally used to evaluate the degree of permanent dental development is that proposed by Demirjian, Goldstein, and Tanner (Demirjian et al., 1973), based on an analysis of a sample of French-Canadian children. The original method evaluates the degree of calcification of the seven teeth in the left mandibular hemiarch, excluding the third molar, from radiographic records. Eight maturation stages (A to H) are established for each tooth, from the start of crown calcification to the root apex closure. Each tooth is attributed a formation stage, then converted into a score depending on the sex, following the same mathematical technique used to evaluate skeletal development by the Tanner-Whitehouse method (Tanner et al., 1975). The scores of the seven teeth are added to obtain the so-called dental maturity score on a scale of 0 to 100. This score is transformed through the corresponding tables into the dental age. The method has the disadvantage that it does not include a valuation of the third molars, so can only be used for preadolescent ages. Subsequently, the same author has produced updates to the original method, proposing a valuation system for four teeth (both premolars and molars) with different standards (Demirjian, 1976).

The developmental stages of tooth crowns and roots are converted to dental age with the use of tables. Estimated chronological age may be calculated as the mean of all the “tooth” ages. Demirjian’s method only covers the age span 3–16 years; and because of the limited number of teeth and developmental stages in the higher age groups, this method has to be used with caution in children older than 12 years. This method is widely accepted as the maturity scoring system can be applied universally for both boys and girls.

The third molar in age assessment

In a study carried out by the Research Committee of the American Board of Forensic Odontology evaluated precision in age assessment from the development state of the lower third molar, valued according to the Demirjian method. According to this study, stages A to D (up to complete crown formation) and stage H (complete apex closure) would show respectively a strong probability that the individual is younger or older than 18 years.

Age estimation using Demirjian’s method

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Forensic age estimation also has application in living individuals in whom the chronologic age is disputed. Demirjian’s method is widely used in dental age estimation of children and adolescents and assesses tooth development/calcification. It has the potential to answer a number of legal questions, for example, “Is the boy < 14 years?” “Has the individual reached the age of majority (18 years)?” The method makes use of mandibular permanent teeth on the

left side — from the central incisor to the 3rd molar. If any tooth is missing on the left side, the corresponding right-side tooth may be utilized.
Compare the radiograph to the 'Tooth Development Chart' and assign each tooth any one of ten developmental stages (0, 1, 2, 3, 4, 5, 6, 7, 8 or 9). Tooth development is a continuous process and teeth on the radiograph may not always match those on the developmental chart. To simplify comparison, the developmental stages are defined by certain criteria. Each developmental stage may have one, two or three criteria marked (a), (b) and (c).

a) If only one criterion is given, this must be observed on the radiograph in order to select the stage
b) If two criteria are given, the first one must be observed on the radiograph in order to select the stage
c) If three criteria are given, the first two of them must be observed on the radiograph for the stage to be selected

In borderline cases, the earlier stage is always considered.

Stage 0

(a) Dental calcification has not yet begun.

Stage 1

(a) The bone crypt has formed, but no sign of the tooth germ.

Stage 2

(a) In both uniradicular and multiradicular teeth, a beginning of calcification is seen at the superior level of the crypt, in the form of inverted cone or cones. There is no fusion of these calcified points.

Stage 3

(a) Fusion of the calcified points forms one or several cusps, which unite to give a regularly outlined occlusal outline.

Stage 4

(a) Enamel formation is complete at the occlusal surface. Its extension and convergence towards the cervical region is seen.
(b) The beginning of dentinal deposit is seen.
(c) The outline of the pulp chamber has a curved shape at the occlusal border.

Stage 5

(a) The crown formation is completed down to the cemento-enamel junction.
(b) The superior border of the pulp chamber in uniradicualr teeth has definite curved form, being concave towards the cervical region. The projection of the pulp horns, if present, gives an outline like an umbrella top. In molars, the pulp chamber has a trapezoidal form.
(c) Beginning of root formation is seen in the form of a spicule.

Stage 6

Uniradicular teeth

(a) The walls of the pulp chamber now form straight lines, whose continuity is broken by the presence of the pulp horn, which is larger than in the previous stage.
(b) The root length reaches at least 1/3rd of the crown height.

Multiradicular teeth

(a) Initial formation of the radicular bifurcation is seen in the form of either a calcified point or semi-lunar shape.
(b) The root length reaches at least 1/3rd of the crown height.

Stage 7

Uniradicular teeth

(a) The walls of the pulp chamber now form a more or less isosceles triangle. The apex ends in a funnel shape.
(b) The root length is equal to or greater than the crown height.

Multiradicular teeth

(a) The calcified region of the bifurcation has developed further down from its semi-lunar stage to give roots a more definite and distinct outline, with funnel shaped endings.

(b) The root length is equal to or greater than the crown height.

Stage 8

(a) The walls of the root canal are now parallel (distal root in molars).

(b) The apical ends of the root canals are still partially open (distal root in molars).

Stage 9

(a) The apical end of the root canal is completely closed (distal root in molars).

(b) The periodontal membrane has a uniform width around the root and apex.

Corresponding to the selected Development Stage, and based on the sex of the subject, each tooth is given a numerical score (refer 'Scoring Table'). Eight numerical scores are obtained (one score for each tooth). These scores are added to obtain a total maturity score. This total score is usually between 0–100. The total maturity score (S) is then substituted in one of the following sex-specific formula to derive the age.

Indian Formulas for Age Estimation (developed on a sample of 165 males and 296 females aged 7 to 25 years):

1. For males, Age = $27.4351 – (0.0097 \text{ X } S^2) + (0.000089 \text{ X } S^3)$
2. For females, Age = $23.7288 – (0.0088 \text{ X } S^2) + (0.000085 \text{ X } S^3)$

Where S= addition of maturity scores of all the eight teeth.

This is the formula to determine age in Indian Population. The study derived its sample primarily from the state Karnataka but also had subjects from about 20 Indian states. So, it is quite comprehensive in terms of diversity. It was tested both on other Southern Indian (Tamil) and Northern Indian (Uttar Pradesh) samples and found to be as accurate as it was in the study. Considering certain population similarities between India and Nepal, the author believe that it can be guardedly applied in Nepal also (particularly, it should be applicable on Brahmin, Chhetri, and Terai populations, although the author doubts it can be used on Newars and Rai, Limbu, Magar, etc.

A study has been conducted at a medical college of Gandaki province of Nepal including 352 OPGs of Nepalese of ages five to 23 years (169 males and 183 females) and equations derived from the maturity score using Demirjian's 8-teeth method. (table 9) (Subedi N et al)

Table 9. Regression equations for males and females

Group	Regression Equations [Age (years) = $\beta_0 + \beta_1 (MS) + \beta_2 (MS)^2 + \beta_3 (MS)^3$]	R^2	Mean Absolute error	SD (real age-estimated age
Males 5 to 18 years (n=131)	Age (years)= $0.00004406 * S^3 – (0.00731862 * S^2) + (0.51569745 * S) – 5.3054497$	0.94	0.747	0.644
Males 5 to 23 years (n=169)	Age (years) = $0.00011193 * S^3 – (0.01970349 *S)^2 + (1.2258773 * S) – 18.163356$	0.94	1.024	0.863
Females 5 to 18 years (n=121)	Age (years) = $0.00001003 * S^3 – (0.00033367 *S)^2 + (0.06314527 *S) +3.7441727$	0.89	0.886	0.925
Females 5 to 23 years (n=183)	Age (years) = $0.00015623 *S^3 – (0.02830971 *S)^2 + (1.7565044 *S) – 28.460225$	0.89	1.231	1.416

Tooth development chart (For scoring of the nine teeth)

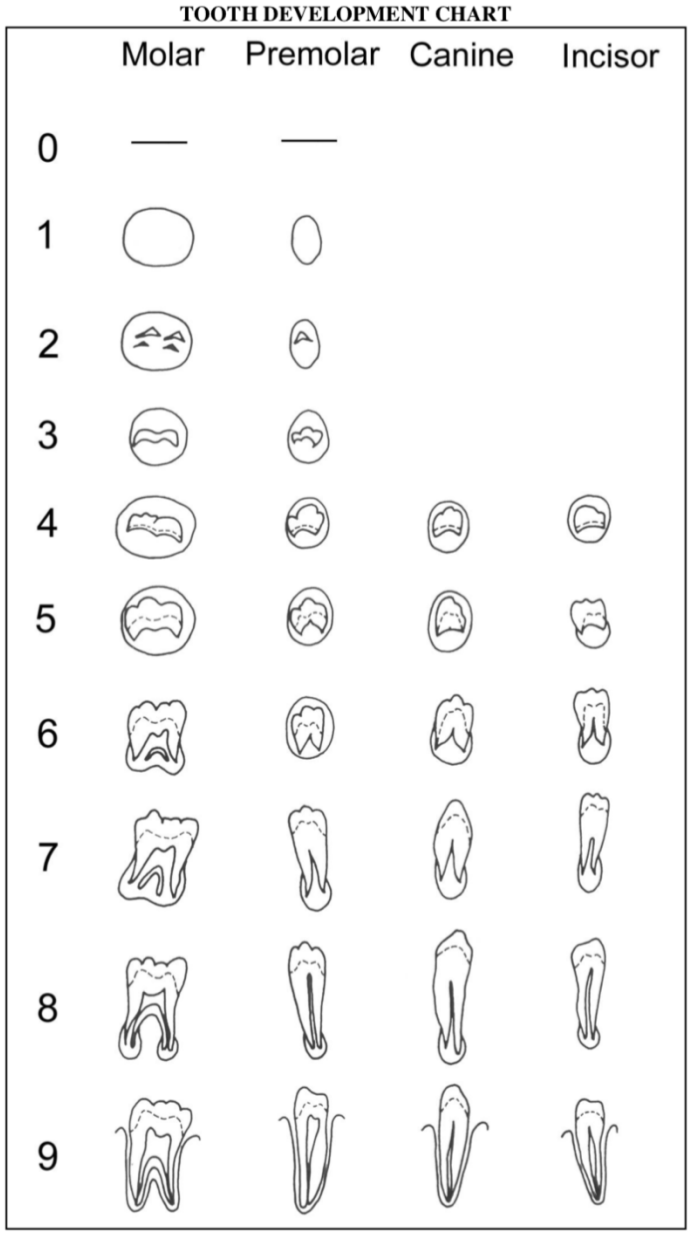


Table 10a: Maturity Scores for Females for Demirjian's method								
Stage	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
0								6.40
1							2.57	7.74
2					2.43			8.92
3				2.56	3.43		2.65	9.31
4			2.55	3.54	3.83		4.10	10.22
5	2.58	2.65	3.15	5.09	5.75	2.58	6.51	11.04
6	3.10	4.54	5.40	6.31	6.81	3.25	8.00	12.65
7	5.02	5.40	7.19	8.09	8.70	4.25	9.13	13.77
8	6.66	7.02	9.22	9.82	10.80	6.88	11.00	14.45
9	10.61	10.89	11.99	12.29	12.79	10.94	13.84	16.65

Table 10b: Maturity Scores for males for Demirjian's method								
Stage	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
0							1.70	6.19
1					1.69		2.98	7.64
2				1.70	2.27		3.41	8.28
3			1.70	1.98	3.41		4.88	9.89
4			2.67	3.52	3.41		4.88	9.89
5	2.31	2.55	4.34	5.19	5.59	2.13	6.69	11.17
6	4.35	4.71	6.14	6.47	6.96	3.73	7.89	12.25
7	5.16	5.75	7.59	8.18	8.68	4.94	9.08	13.66
8	6.56	6.97	9.52	9.84	10.64	7.00	11.13	14.07
9	10.68	10.91	12.56	12.57	13.11	11.22	13.63	15.32

Age estimation from attrition of permanent molars

Teeth undergo attrition with increasing age and the structures cannot be remodeled like other hard tissues. Therefore, the severity of attrition can be used to determine age of the individual. In the first two decades of life, age can be determined by the sequence of eruption and calcification of teeth and also by the radiological examination of bones. After the third decade, those parameters cannot predict age accurately. Therefore, this method can be very useful to determine the age beyond the third decade.

The average score of attrition (ASA) of the maxillary first and second permanent molars on either side can calculated based on the chart given by Li and Ji. The ASA is the average stage of the attrition on all cusps of a molar when evaluating the attrition degree from stages O-7 for each cusp. The eighth and ninth stage of attrition are estimated from the attrition condition of the entire occlusal surface. The graduated standards are as follows:

Stage 0: No attrition. Cusp is sharp. Gullies and ridges are clear.
Stage 1: Slight attrition on the top and ridges of the cusp.
Stage 2: Cusp appears obtuse or a limited oblique facet appears on it.
Stage 3: The great part of cusp is worn away. The wear facet is depressed slightly or obviously, and may connect with one or more other facets.
Stage 4: Dentine appears as a spot in which the average diameter is I 1 mm.
Stage 5: Dentine appears as a spot in which the average diameter is > 1 mm, and the attrition plane is level or sunk deeply.
Stage 6: One exposed dentine spot coalesces with another one and/or cusp is almost entirely worn away.
Stage 7: One exposed dentine spot coalesces with two others and/or cusp is entirely worn away.
Stage 8: Exposed dentine appears as a circle and there is a small starlike island of enamel within it. The secondary dentine may also be exposed.
Stage 9: Dentine is exposed on the entire occlusal surface and the secondary dentine has been exposed.

The score thus obtained can be used to determine age from the formula derived from regression analyses.

A well proven Indian population based formula is as follows: (Ajmal et al)

For maxillary teeth:

First molar: Age = 36.39 + 1.93M1

Both first and second molars: Age= 25.99+ 2.09M1+ 1.39 M2

For Mandibular teeth:

First molar: Age= 24.58+ 3.78M1
Second molar: Age= 22.16 + 4.26M2
Both Molars: Age= 20.08 +2.46M1+2.15M2
{M: ASA of the molar}

A study conducted in a tertiary hospital of Gandaki Province to estimate age from average stage of attrition of permanent molars in selected Nepalese population has derived equations using maxillary and mandibular first and second molars. The equations are presented in table 11. (Subedi N et al)

Table 11: Linear regression for Age in years and from average of stage of attrition in a selected Nepalese sample in Gandaki Province of Nepal (n=451, males 220 and females 231).

Teeth Used	Regression Equations ($y = \alpha + \beta_1 X_1 + \beta_2 X_2$)	r	Mean of Difference of real age and estimated age.	SD of difference of real age and estimated age.
UM1	Age = 13.41 + 10.14 X ASA of UM1	0.92	4.21	3.27
UM2	Age = 13.97 + 11.29 X ASA of UM2	0.89	4.86	4.01
UM1 & UM2	Age = 11.95 + 6.86 X ASA of UM1 + 4.26 X ASA of UM2	0.88	3.82	3.03
LM1	Age = 16.55 + 8.57 X ASA of LM1	0.77	6.76	5.63
LM2	Age = 10.94 + 12.23 X ASA of LM2	0.86	5.47	4.47
LM1 & LM2	Age = 9.36 +2.96 X ASA of LM1 + 9.3 X ASA of LM2	0.77	5.17	4.2

*UM1= Upper first permanent molar, UM2= Upper second permanent molar, LM1=Lower first mandibular molar, LM2=Lower second permanent molar.

Radiological examination

The assessment of bone age is most commonly based on x-rays of the hand and wrist, which are compared to one of two different but similar reference atlases by Greulich and Pyle (GP) and Tanner and Whitehouse (TW2). Skeletal age is determined by studying the development stage of bones. The fusion/maturation of the bones is allocated some developmental stages and age estimation is done.

When the population-based studies fulfilling the criteria of Solari & Abramovitch based on the standard methods are not available, radiological age estimation is based upon the study of growth in individual bones.

Growth in individual bones (Ossification of bones)

The bones of the human skeleton are pre-formed in hyaline cartilage. This soft tissue model is gradually converted into hard osseous tissue by the development of osteogenesis, mostly from the center, from which the process of transformation spreads, until the whole skeleton is ossified. The appearance of such centers of ossification is spread over a long period of time. A large number are first seen in embryonic life, some appear much later in prenatal life, and others after birth.

As a rule, ossification begins centrally in an epiphyses and spreads peripherally as it gets bigger. At first, it is entirely amorphous, rounded and pinhead sized. As it grows, it takes the osteological details of the bone.

Some bones are ossified from a single center eg. Carpus and tarsus. Most bones are ossified from several separate centers, one of which appears near the middle of the future bone. This center is concerned with progressive ossification towards the bone ends. These terminal regions are ossified by separate centers, sometimes multiple; they are said to be secondary centers.
Typically, a long bone such as the tibia has become ossified throughout its shaft (diaphysis) at birth, whereas its two ends (epiphyses) are later ossified by secondary centers. A layer of hyaline cartilage (epiphyseal plate) persists between the diaphysis and the epiphysis. The bone increases in length at this epiphyseal plate or disc (growth plate or growth cartilage) until its final dimensions are attained. The process of union of epiphyses and diaphysis is called fusion. Union is a process, not an event. Union of bone can be divided into various stages from: Non-union, Starting of Union to completely united. The union in long bones is interpreted as non-united, uniting (1/4, ½, ¾ etc), recently united and united, depending on the stage of union.
The long limb bones show epiphyseal arrangement at both ends, while metacarpals, metatarsals, phalanges, clavicles and ribs possess an epiphysis at one end only. In some bones, the epiphyseal centers at one or both ends are more complex, eg. in the proximal end of the humerus, which is wholly cartilaginous at birth, three separate centers appear during the childhood. They soon unite to form a single epiphyseal mass, which later fuses to diaphysis.
For determining the age, X-rays of the shoulder, elbow, wrist, hip, knee, ankle, pelvis and skull should be taken in anteroposterior direction.
There are variations of the age dependent changes and there may be maturity imbalance between bones from different parts of the same individual. There is only a central tendency with a normal range of variability and the variability increases with age.
As a rule, the ageing of bones is more accurate with respect to the appearance of centers of ossification that is with respect to the union of epiphyses.
In the long bones of upper limbs, the union occurs earlier in the elbow joint and later in the wrist joint. Head of the humerus is the last long bone epiphyses to unite. In the long bones of the lower limbs, the union occurs later at the knee joint and earlier at the hip and ankle joints.

Table 12: Appearance of centers of ossification and union of bones and epiphyses

Age	Appearance of center of ossification	Union of bone and epiphyses
5th year	Head of radius, trapezoid, scaphoid	Greater tubercle fuses with head of humerus
6th year	Lower end of ulna, trapezium	Rami of pubis and ischium unite
9th year	Olecranon	
9th to 11th year	Pisiform	
11th year	Lateral epicondyle of humerus	
13th year	Separate centers in triradiate cartilage of acetabulum	
12th to 14th year	Lesser trochanter of femur	
14th year	Crest of ilium, head and tubercles of ribs	Medial epicondyle of humerus: lateral epicondyle with trochlea, patella complete

15th year	Acromion	Coracoid with scapula, triradiate cartilage of acetabulum
16th year	Ischial tuberosity	Lower end of humerus, olecranon to ulna, upper end of radius, metacarpals, proximal phalanges
18th year		Head of femur, lesser and greater trochanter of femur, acromion, lower end of ulna
18th to 19th year	Inner end of clavicle	Lower end of femur, upper end of tibia and fibula, head of humerus, lower end of radius
20 to 21st year		Iliac crest, Inner end of clavicle, ischial tuberosity, head of ribs

Variations of the maturity of the bones occur depending on the health, hereditary, nutritional, infectious diseases, metabolic disorders, physical activity, race, sex, endocrine and environmental factors. Multiple criteria of skeletal age should be employed whenever possible. An estimated skeletal age based on appearance of ossification centers and union of epiphyses must always be expressed in plus or minus terms, eg. 15±1 years (fifteen years plus or minus one year).

Skeletal development in the female can be in advance of the male up to one year, while dental development may differ only from one to four months. In males, dental and osseous ages are almost similar, but in females, osseous age is in advance of the dental age. In tropical climates, ossification centers and epiphyseal union takes place about 2 years earlier than in temperate zones.

The union of epiphyses as seen in radiographs appear earlier approximately by about plus or minus six months than the periods of fusion indicated by anatomical evidence. It is because of the fact, that towards the end of the growth period, the epiphyseal plate of the cartilage becomes very thin and irregular in outline and may not show on radiograph. In an individual bone, once union has begun, it will be completed in about 12 to 18 months.

Age determination can be also be done using the status of formation and fusion of epiphyses of bones of the hand and feet. The findings of the Nepalese study by Shrestha M et al can be implied to determine the age of Nepalese individuals till the standard population based studies testing the established methods are available.

Based on the Nepalese study carried out in 222 children (103 males and 119 females) between the age group of 10 to 20 years in Kavre district of Nepal, following inferences were made:

- The fusion of epiphyses in >50% of the children at medial epicondyle of the left humerus is at the age of 14-15 years in males and 13-14 years in females. Fusion was seen in 100% cases at 15-16 years in males and 14-15 years in females.
- The fusion of epiphyses in >50% of the children at medial epicondyle of the left humerus is at the age of 14-15 years in males and 12-13 years in females. Fusion was seen in 100% cases at 15-16 years in males and 13-14 years in females.
- The fusion of epiphyses in >50% of the children at the head of radius is at the age of 14-15 years in males and 13-14 years in females. Fusion was seen in 100% cases at 15-16 years in males and 14-15 years in females.
- The fusion of epiphyses in >50% of the children at the olecranon is at the age of 14-15 years in males and 13-14 years in females. Fusion was seen in 100% cases at 15-16 years in males and 14-15 years in females.
- The fusion of epiphyses in >50% of the children at the distal end of radius is at the age of 17-18 years in males and 16-17 years in females. Fusion was seen in 100% cases at 18-19 years in males and 17-18 years in females.

- The fusion of epiphyses in >50% of the children at the distal end of ulna is at the age of 17-18 years in males and 13-14 years in females. Fusion was seen in 100% cases at 18-19 years in males and 17-18 years in females.
- The fusion of epiphyses in >50% of the children at the first metacarpal of the left hand is at the age of 15-16 years in males and 14-15 years in females. Fusion was seen in 100% cases at 17-18 years in males and 15-16 years in females.
- The fusion of epiphyses in >50% of the children at head of the metacarpals of left hand is at the age of 16-17 years in males and 15-16 years in females. Fusion was seen in 100% cases at 18-19 years in males and 16-17 years in females.
- The fusion of epiphyses in >50% of the children at phalanges of left hand is at the age of 16-17 years in males and 15-16 years in females. Fusion was seen in 100% cases at 17-18 years in males and 16-17 years in females.
- The fusion of epiphyses in >50% of the children at the iliac crests is at the age of 19-20 years in males. Fusion was seen in 100% cases at 19-20 years in females.
- The fusion of epiphyses in >50% of the children at the ischial tuberosity is at the age of 19-20 years in males. Fusion was seen in 100% cases at 19-20 years in females.

Sternum

The four pieces of the body of the sternum fuse with one another from below upwards between 14 to 25 years. At about 40 years, the Xiphoid unites with the body. The manubrium fuses with the body in old age at about 60 years.

Ribs

Progressive ossification of sternal rib ends of the costal cartilages correlate with increasing age within 5-8 years of real age.

Hyoid bone

The greater cornu of the hyoid bone unites with the body between 40 to 60 years.

Skull

- Lateral and occipital fontanelles usually close within the first two months.
- Posterior fontanelle closes between 1.5 to 2 years.
- The condylar portions of occipital bone fuses with the squama at the third year, and with the basioccipital at the fifth year.
- The metopic suture closes about the third year, but in 5-10% cases, it persists.
- The basio-occipital fuses with the basio-sphenoid at about 18-21 years.

In the vault

Closure of the sutures begins on the inner side 5 to 10 years earlier than on the outer side. The coronal, sagittal, and lambdoid sutures start to close on their inner side at about the age of 25 years. On the outer side, fusion occurs in the following order: posterior one third of the sagittal suture at about 30-40 years; anterior one third of the sagittal and lower half of the coronal at about 40-50 years; and middle sagittal and upper half of the coronal at about 50 to 60 years. The lambdoid suture starts closing near the lambda and the union is often completed at about 45 years. The squamous part of the temporal bone usually fuses with its neighbor by age of 60 years.

Suture closure in skull occurs later in females than in males.

Sacrum

Centers appear in upper segments in third month. The five sacral vertebrae are separated by cartilage until puberty, when the lateral portions grow together. After this, fusion of epiphyses takes place and ossification of intervertebral discs extends from below upwards. The sacrum becomes a single bone between 21 and 25 years. A gap may persist between S1 and S2 until 32 years due to “lapsed union”.

The Greulich and Pyle method

The Greulich and Pyle method (Greulich & Pyle, 1959) is an atlas-based method. The assessment is performed by comparing a person's left hand-wrist radiograph with an atlas containing standard radiographs for a range of skeletal ages in which the development stages of each bone is described in 2 different atlases separately for males & females. The method requires the assessor to work systematically through the chosen radiograph, comparing each of 31 bones and sesmoids in the hand-wrist with the standards in the atlas that varies with the race, age and sex. Then an age is assigned to each bone using data from tables associated with the standard that contains the closest match to the bone. If no match is found for a bone, the age is estimated from the closest matching radiographs. It is applicable to the child from birth to 18 years old.

Tanner Whitehouse method

The Tanner-Whitehouse method is based on left hand and wrist radiography. Many studies have shown that it is more precise than the Greulich and Pyle method and can be used in various ethnic groups. Generally, in order to determine the bone age it is used the left hand and wrist radiography. The bone age of the left hand precedes that of the right hand because the right hand is more frequently involved in injury than the left one. The score is assigned to 20 of the epiphyses in the left hand and wrist radiographs compared with the standard.

The bones examined are: distal radius, distal ulna, first, third and fifth metacarpals, proximal phalanges of the thumb, third and fifth fingers, middle phalanges of the third and fifth fingers, distal phalanges of the thumb, third and fifth fingers, the seventh carpal bones: capitate, hamate, triquetral, lunate, scaphoid, trapezium and trapezoid. Each bone, conformed to Tanner-Whitehouse method, is graded into 8 or 9 maturity stages. Staging are assigned pursuant the rating system of the Tanner-Whitehouse method. If no sign of the bone are presented, the lowest rating is given.

The epiphyseal region are staged by distinction of the size, shape, density, smoothness or thickening of the borders, thickness of epiphyseal line, extent of fusion and capping. This method uses a detailed analysis of each individual bone. Each ROI (region of interest) is divided in three parts namely epiphysis, metaphysis and diaphysis. The development of each ROI is represented by letters A, B, C, D, E, F, G, H and I. Stage A represents bone is absent, Stage B represents single deposit of calcium, Stage C represents center is distinct in appearance, Stage D represents maximum diameter is half or more the width of metaphysic, Stage E represents border of the epiphysis is concave, Stage F represents epiphysis is as wide as metaphysis, Stage G represents epiphysis caps the metaphysis, Stage H represents fusion of epiphysis and metaphysis has begun and Stage I represents epiphyseal fusion completed. By adding the scores of all ROIs, an overall maturity score is obtained. This score is correlated with the bone age differently for males and females. The individual scores of 20 bones corresponding to the stages, both for the boys and for the girls are given in tables presented below.

The total scores of the 20 bones are totalled and, by reference to gender-dependent standard tables, the total maturity score (on a scale of 0 to 1000) is converted into an individual bone age. The maturity score of the boys and girls and the bone age calculation from the conversion table is represented in the tables in annex.

Tanner and colleagues published a revised 3rd edition for bone ageing in 2001 (TW3). This updated the relationship of the SMS (skeletal maturity score) to bone age to deal with the secular trend that had occurred in skeletal maturation since the previous edition. However, this new version has received little publicity. The descriptions and manual ratings remain the same for TW2 and TW3, and the calculation of the SMS is the same. However, the centile charts for RUS SMS against age have changed between versions 2 and 3.

Age estimation in the clavicle

To answer the question of whether a person has reached the age of 18 years, the ossification status of the medial epiphysis of the clavicle can be evaluated, because all other examined developmental systems may already have completed their growth by that age. It is stated that chest radiographs can essentially provide a basis for assessing clavicular ossification. If overlap in posterior-anterior views impedes evaluation additional oblique images should be taken to facilitate age estimation.

The ossification status of the medial end of clavicle can be categorised as five stages as proposed by Schmeling (2004).

Stages in this system correspond with:

Stage 0: there is no ossification of the epiphyseal centre of the clavicle.

Stage 1: the ossification centre has not yet ossified (incomplete ossification of the epiphyses).

Stage 2: the ossification centre has ossified, the epiphyseal cartilage has not ossified.

Stage 3: the epiphyseal cartilage is partially ossified.

Stage 4: the epiphyseal cartilage is fully ossified.

Stage 5: the epiphyseal cartilage has fused completely and the epiphyseal scar is no longer visible.

Assessments of age using available forms of documentation, local knowledge and information

Before going to the medical measures of age estimation, the age of the person can be ascertained by obtaining documents like date of birth or such which provides indication of their approximate age. The legal provision can specify which types of documents can be acceptable as evidence of age of the person. Some of the documents may be birth certificates, school records, health clinic records etc.

Expert Report

According to the recommendations of the Study Group on Forensic Age Diagnostics (Schmeling et al., 2008) the collected findings and the determined stages are to be presented in detail in the expert report. The used references, stage classifications and reference studies are to be mentioned.

Reference studies used for forensic age estimation should meet the following requirements:

- Adequate sample size
- Proven age of subjects
- Even age distributions of subjects
- Analysis separately for both sexes
- Information on the time of examination
- Clear definition of the examined features
- Detailed description of the methods
- Data on the reference population regarding ethnicity, socioeconomic status, state of health
- Data on the sample size, mean value, and range of scatter for each examined feature

Examples of reference studies are Greulich and Pyle (1959), Gunst et al. (2003), Kahl and Schwarze (1988), Mincer et al. (1993), Schmeling et al. (2004), Tanner et al. (2001) etc.

Preparing the reports

The objective of the expert forensic report is to provide the most probable age of the individual and/or the probability that the stated age is the actual age or that the individual's age is above the penal age limit.

The expert report has to quote the methods and the reference studies the age estimation is based on. The influence of ethnicity, geographic origin, nutrition, socioeconomic status and any development disorders should be discussed in the report and possibly, a quantitative assessment of any such factors should be given.

The degree of accuracy of the estimation and age range should also be given.

Annex

Table 13a: Twenty Bone Tanner-Whitehouse Maturity Score (MS) for Boys								
Bone	Boys							
	B	C	D	E	F	G	H	I
Radius	15	17	21	27	48	77	96	106
Ulna	22	26	30	39	56	73	84	X
First Metacarpal	4	5	11	19	24	28	30	32
Third Metacarpal	3	4	6	10	16	22	23	25
Fifth Metacarpal	3	3	6	12	17	21	23	25
Proximal Phalanx of the Thumb	4	5	8	15	23	28	30	32
Proximal Phalanx of the Third Finger	3	4	6	13	20	23	24	26
Proximal Phalanx of the Fifth Finger	3	3	6	13	19	22	23	25
Middle Phalanx of the Third Finger	3	4	7	13	19	22	23	25
Middle Phalanx of the Fifth Finger	4	4	8	14	19	21	22	23
Distal Phalanx of the Thumb	4	4	7	14	23	30	31	33
Distal Phalanx of the Third Finger	3	4	6	10	16	21	22	24
Distal Phalanx of the Fifth Finger	3	4	7	11	16	20	21	23
Capitate	60	62	65	71	79	89	116	X
Hamate	42	44	49	59	70	81	92	106
Triquetral	7	10	17	28	38	45	62	X
Lunate	10	13	20	27	36	44	60	X
Scaphoid	14	18	23	30	35	42	58	X
Trapezium	12	15	21	28	34	39	47	59
Trapezoid	14	16	20	23	32	39	56	X

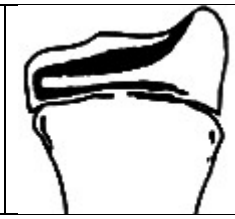
Table 13b: Twenty Bone Tanner-Whitehouse Maturity Score for Girls								
Bone	Girls							
	B	C	D	E	F	G	H	I
Radius	17	19	25	33	54	85	99	106
Ulna	22	26	30	39	60	73	80	X
First Metacarpal	5	6	11	18	24	29	31	33
Third Metacarpal	3	5	7	11	17	23	24	26
Fifth Metacarpal	3	4	7	12	18	22	24	25
Proximal Phalanx of the Thumb	5	5	8	14	24	29	30	32
Proximal Phalanx of the Third Finger	4	4	7	13	20	24	25	26
Proximal Phalanx of the Fifth Finger	4	4	7	13	19	23	24	25
Middle Phalanx of the Third Finger	4	4	7	13	20	23	24	25
Middle Phalanx of the Fifth Finger	4	5	8	14	20	22	22	23
Distal Phalanx of the Thumb	5	5	8	15	24	31	32	34
Distal Phalanx of the Third Finger	3	4	6	10	17	22	23	24
Distal Phalanx of the Fifth Finger	3	4	7	11	17	21	22	23
Capitate	53	56	61	67	76	85	113	X
Hamate	44	47	53	64	74	85	97	109
Triquetral	8	12	19	28	36	46	63	X
Lunate	10	14	20	27	35	46	60	X
Scaphoid	13	17	23	29	36	44	57	X
Trapezium	12	14	20	25	32	39	49	59
Trapezoid	13	16	20	24	31	40	57	X

Table 13c: Tanner-Whitehouse Boys Bone Age (BBA) for Given Maturity Score (MS)																
MS	114	116	119	123	126	129	133	136	139	142	146	150	154	159	163	168
BBA	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5
MS	172	176	181	185	190	195	200	205	210	215	220	226	231	236	242	247
BBA	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1
MS	252	258	264	270	276	282	287	292	298	303	308	314	319	325	331	337
BBA	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7
MS	343	349	355	360	366	372	378	384	390	396	402	409	415	422	428	435
BBA	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3
MS	441	447	454	460	466	472	477	483	489	495	501	507	513	520	526	533
BBA	7.4	7.5	7.6	7.7	7.8	79.0	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9
MS	540	546	553	560	566	573	580	587	594	601	608	615	622	629	636	643
BBA	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5
MS	650	657	664	671	678	684	690	697	703	711	718	725	732	740	747	754
BBA	10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9	12.0	12.1
MS	761	768	774	781	788	795	802	809	817	823	830	836	842	849	855	861
BBA	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.2	13.3	13.4	13.5	13.6	13.7
MS	867	873	879	884	889	895	900	906	911	916	921	926	931	936	940	944
BBA	13.8	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1	15.2	15.3
MS	948	952	956	959	963	967	970	973	976	979	981	983	985	987	989	991
BBA	15.4	15.5	15.6	15.7	15.8	15.9	16.0	16.1	16.2	16.3	16.4	16.5	16.6	16.7	16.8	16.9
MS	992	994	995	996	996	997	998	999	999	999	10^3					
BBA	17.0	17.1	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9	18.0					

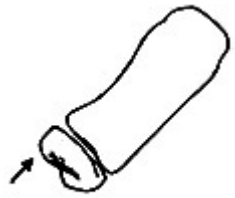
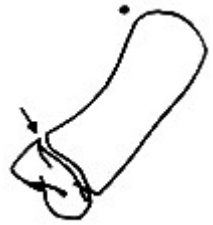
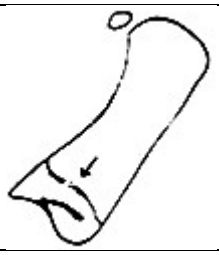
Table 13d: Tanner-Whitehouse Girls Bone Age (GBA) for Given Maturity Score (MS)																
MS	131	136	140	146	152	159	163	172	179	186	192	199	206	213	220	226
GBA	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5
MS	233	240	247	253	260	267	274	281	287	293	299	303	311	317	324	331
GBA	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1
MS	338	345	351	357	363	370	376	382	389	395	402	408	414	420	426	432
GBA	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7
MS	438	444	450	456	462	468	474	480	485	491	497	503	510	516	522	529
GBA	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3
MS	535	541	547	553	559	565	571	578	585	592	600	608	617	625	634	643
GBA	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9
MS	653	662	670	680	690	700	710	721	731	742	752	762	772	783	794	803
GBA	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5
MS	812	821	830	838	845	852	859	866	872	879	885	891	898	903	908	913
GBA	10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9	12.0	12.1
MS	918	923	928	932	937	940	944	948	953	956	960	963	966	969	972	974
GBA	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.2	13.3	13.4	13.5	13.6	13.7
MS	976	979	981	982	984	986	987	989	990	991	993	994	995	995	996	996
GBA	13.8	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1	15.2	15.3
MS	997	997	998	998	999	999	10^3									
GBA	15.4	15.5	15.6	15.7	15.8	15.9	16.0									

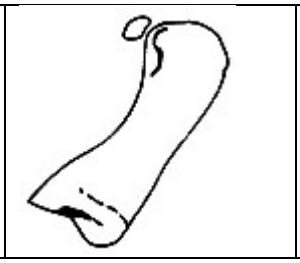
Table 14: Description of Individual bones of Tanner and Whitehouse staging

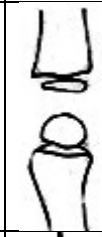
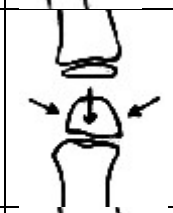
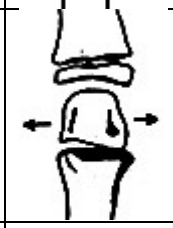
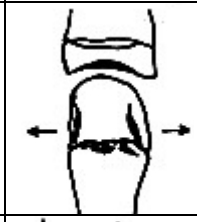
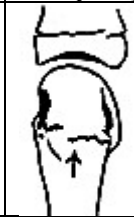
1. Radius		
Stage		
B		The center is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The center is distinct in appearance and oval in shape with a smooth continuous border.
D		The maximum diameter id half or more the width of the metaphysis. The epiphysis has broadened chiefly at its lateral side, so that this portion is thicker and more rounded, the medial portion more tapering. The centre third of the proximal surface is flat and slightly thickened and the gap between it and the radial metaphysis has narrowed to about a millimetre.
E		A thickened white line has appeared just inside the distal border of the epiphysis; this represents the edge of the palmar surface and the newly appeared bone distal to it is edged of the dorsal surface.
F		The proximal border of the epiphysis is now differentiated into palmar and dorsal surface; the palmar surface is visible as a broad irregularly thickened white line at the proximal edge of the epiphysis. Both ends of the epiphysis, but particularly the medial one, have grown outward and proximally since the last stage so that the proximal border now conforms to the shape of the metaphysis along most of its extent.
G		The dorsal surface now has distinct lunate and scaphoid articular edges joined at a small hump. The medial border of the epiphysis has developed palmar and dorsal surfaces for articulation with the ulnate epiphysis; either palmar or dorsal surface may be the one which projects medially, depending on the position of the wrist. The proximal border of the epiphysis is now slightly concave.
H		The epiphysis now caps the methaphysis on one (usually the medial) or both sides.

I		Fusion of epiphysis and metaphysis has begun. A line may still be visible composed partly of black areas where the epiphyseal cartilage remains and partly of dense white areas where fusion is proceeding; or the line may have disappeared.

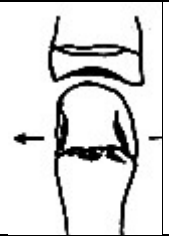
2. Ulna		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance, with a smooth continuous border.
D		The maximum diameter is half or more the width of the metaphysis. The epiphysis is now elongated so that the transverse, medio-lateral diameter is considerably greater than the longitudinal, disto-proximal diameter. proximal and distal borders are both flattened, though not necessarily parallel, so that the epiphysis is usually wedge-shaped with the point facing laterally.
E		The styloid process is now visible as a distinct though small projection.
F		The head of the ulna is now distinctly defined and denser than the styloid process. (Its medial surface usually appears as a thickened white line differentiating it from the styloid process, and there is often a concavity of the proximal and/or distal border of the epiphysis where the head and styloid meet.) The border adjacent to the radial epiphysis is flattened.
G		The epiphysis is now as wide as the metaphysis. The proximal border of the epiphysis and distal border of the metaphysis overlap in their central one-third.
H		Fusion of the epiphysis and metaphysis has begun. The line between epiphysis and metaphysis may be still visible composed partly of black areas, usually on the styloid side, where the epiphyseal cartilage remains, and partly of dense white areas where fusion is proceeding; or the line may have disappeared.

3. First Metacarpal		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposit. The border is ill-defined.
C		The epiphysis is distinct in appearance and oval in shape, with a smooth continuous border.
D		The maximum diameter is half or more the width of the metaphysis.
E		The epiphysis is as wide as the metaphysis. A concavity is present in the proximal border. (This is due to the first appearance of palmar and dorsal surfaces of the epiphysis, though as yet these surfaces themselves are not distinct.)
F		The differentiation of the proximal surface into palmar and dorsal portions is now distinct and the full extent of the dorsal surface can be made out; due to the rotation of the thumb in its position on the film, these surfaces appear as latero-dorsal and medio-palmar. The saddle formed by these surfaces conforms to the adjacent border of the trapezium bone. (Towards the end of this stage the medial border of the epiphysis changes from a rounded shape to a flat distinct border.)
G		The epiphysis caps the metaphysis on one or both sides; the capping is usually seen better on the medial than on the lateral side, due to the rotation of the thumb in positioning the hand.
H		Fusion of epiphysis and metaphysis has begun. A line is still visible, composed partly of black areas where the epiphyseal cartilage remains and partly of dense white areas where fusion has occurred.

I		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

4. Third metacarpal		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The epiphysis is distinct in appearance and rounded in shape with a smooth continuous border.
D		The transverse diameter is half or more the width of the metaphysis.
E		Since the last stage the shape of the epiphysis has chanced from being an oval or semicircle to that of a spade or finger-nail. This occurs by virtue of the lateral, medial and proximal borders of the epiphysis becoming distinct one from another and identifiable by the angles seen at their junctions.
F		It is now possible, in a good film, to distinguish the palmar from the dorsal surface of the epiphysis. Since the last stage the medial and/or lateral edges of the dorsal surface have grown outwards to overlap the palmar surface of the epiphysis. The outlines of the palmar edges now appear as longitudinal thickened white lines.
G		The epiphysis is as wide as, or wider than, the metaphysis. (This stage would seem to be the equivalent of the stage of capping in the epiphysis of the phalanges.)
H		Fusion of the epiphysis and metaphysis has begun. The dark line of the cartilage extends over less than three-quarters of the bone's breadth, but is not entirely obliterated.

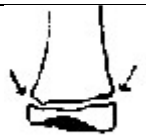
I		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

5. Fifth Metacarpal		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The epiphysis is distinct in appearance and rounded in shape with a smooth continuous border.
D		The transverse diameter is half or more the width of the metaphysis.
E		Since the last stage the shape of the epiphysis has chanced from being an oval or semicircle to that of a spade or finger-nail. This occurs by virtue of the lateral, medial and proximal borders of the epiphysis becoming distinct one from another and identifiable by the angles seen at their junctions.
F		It is now possible, in a good film, to distinguish the palmar from the dorsal surface of the epiphysis. Since the last stage the medial and/or lateral edges of the dorsal surface have grown outwards to overlap the palmar surface of the epiphysis. The outlines of the palmar edges now appear as longitudinal thickened white lines.
G		The epiphysis is as wide as, or wider than, the metaphysis. (This stage would seem to be the equivalent of the stage of capping in the epiphysis of the phalanges.)

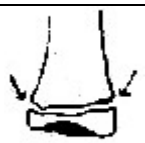
H		Fusion of the epiphysis and metaphysis has begun. The dark line of the cartilage extends over less than three-quarters of the bone's breadth, but is not entirely obliterated.
I		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

6.	**Proximal Phalanx of the Thumb**	
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and disc-shaped, with a smooth continuous border. (Multiple centres may occur whose summed maximum diameters exceed half the width of the metaphysis.)
D		The maximum diameter is half or more the width of the metaphysis.
E		The proximal border is concave and usually thickened. The medial side is longer than the lateral, giving the wedge-shaped appearance.
F		The epiphysis is wider than metaphysis, particularly at the medial side, and follows closely its shape.
G		The epiphysis caps the metaphysis. (The capping is seen better on the medial than on the lateral side.)

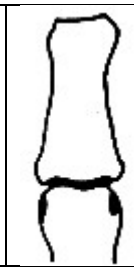
H		Fusion of epiphysis and metaphysis has begun.
I		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

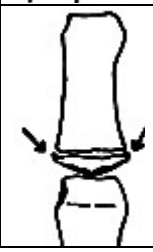
7. Proximal Phalanx of the Third Finger		
Stage		
A		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
B		The centre is distinct in appearance and disc-shaped, with a smooth continuous border.
C		The epiphysis is half or more the width of the metaphysis.
D		The proximal border of the epiphysis is concave and distinctly thickened.
E		The epiphysis is as wide as the metaphysis and follows closely its shape, although it does not yet cap it at the edges.
F		The epiphysis caps the metaphysis.
G		Fusion of epiphysis and metaphysis has now begun. A line is still visible composed partly of black areas where the epiphyseal cartilage remains and partly of dense white areas where fusion is proceeding.

H		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

8. Proximal Phalanx of the Fifth Finger		
Stage		
A		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
B		The centre is distinct in appearance and disc-shaped, with a smooth continuous border.
C		The epiphysis is half or more the width of the metaphysis.
D		The proximal border of the epiphysis is concave and distinctly thickened.
E		The epiphysis is as wide as the metaphysis and follows closely its shape, although it does not yet cap it at the edges.
F		The epiphysis caps the metaphysis.
G		Fusion of epiphysis and metaphysis has now begun. A line is still visible composed partly of black areas where the epiphyseal cartilage remains and partly of dense white areas where fusion is proceeding.
H		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

9. **Middle Phalanx of the Third Finger**		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and disc-shaped, with a smooth continuous border.
D		The maximum diameter is half or more the width of the metaphysis.
E		The central portion of the proximal border has thickened and grown towards the end of the adjacent phalanx, shaping to its trochlear surface. (This thickened white line represents the dorsal surface of the epiphysis; proximal to it the palmar surface is usually visible on one or both sides as a convex projection. In some positions of the hand, however, these proximal edges of palmar and dorsal surfaces appear superimposed.
F		The epiphysis is as wide as the metaphysis.
G		The epiphysis caps the metaphysis.
H		Fusion of epiphysis and metaphysis has now begun. A line is still visible composed partly of black areas where the epiphyseal cartilage remains and partly of dense white areas where fusion is proceeding.

I		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

10. **Middle Phalanx of the Fifth Finger**		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and disc-shaped, with a smooth continuous border.
D		The maximum diameter is half or more the width of the metaphysis.
E		The central portion of the proximal border has thickened and grown towards the end of the adjacent phalanx, shaping to its trochlear surface. (This thickened white line represents the dorsal surface of the epiphysis; proximal to it the palmar surface is usually visible on one or both sides as a convex projection. In some positions of the hand, however, these proximal edges of palmar and dorsal surfaces appear superimposed.
F		The epiphysis is as wide as the metaphysis.
G		The epiphysis caps the metaphysis.

H		Fusion of epiphysis and metaphysis has now begun. A line is still visible composed partly of black areas where the epiphyseal cartilage remains and partly of dense white areas where fusion is proceeding.
I		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

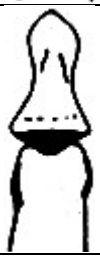
11. Distal Phalanx of the Thumb		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and disc-shaped, with a smooth continuous border.
D		The maximum diameter is half or more the width of the metaphysis.
E		The epiphysis is as wide as the metaphysis. The shape has changed, so that there is now a somewhat flattened distal border and an angulated proximal border. (The change in shape of the proximal border comes about though a down-growth similar to that seen at this stage in the epiphysis of the middle and distal phalanges of the fingers in their central axis. Due to the rotation of the thumb in its position on the film, however, this down-growth appears usually at the proximo-medial edge, although sometimes it may be nearly central.)
F		The proximo-lateral border of the epiphysis is now concave and shapes to the head of the proximal phalanx. (In some positions of the thumb, this border is not visible as such. Instead the articular surface may be seen as a white concave line inside the proximo-lateral border.) On the distal border the medial and lateral surfaces can both be seen, with the base of the terminal phalanx conforming to the saddle shape between them. The epiphysis is now wider than the metaphysis.

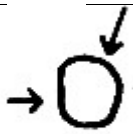
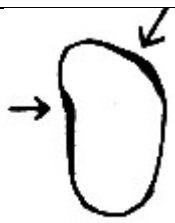
G		The epiphysis caps the metaphysis. (Because of the position of the thumb this better seen on the medial side.)
H		Fusion of epiphysis and metaphysis has now begun. A line is still visible composed partly of black areas where the epiphyseal cartilage remains and partly of dense white areas where fusion is proceeding.
I		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

12. Distal Phalanx of the Third Finger		
Score		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and disc-shaped, with a smooth continuous border.
D		The maximum diameter is half or more the width of the metaphysis.
E		The epiphysis is as wide as the metaphysis. The central potion of the proximal border has grown toward the end of the middle phalanx, so that the proximal border no longer consists of a single convex surface; no differentiation into palmar and dorsal surfaces, however, can yet be seen.
F		Palmar and dorsal proximal surfaces are distinct, and each has shaped to the trochlear articulation of the middle phalanx. The palmar surface appears as a projection proximal to the thickened white line representing the dorsal surface.

G		The epiphysis caps the methaphysis.
H		Fusion of epiphysis and metaphysis has now begun. (A line is still visible, composed partly of black areas where the epiphyseal cartilage remains and partly of dense white areas where fusion is proceeding.)
I		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

13. **Distal Phalanx of the Fifth Finger**		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and disc-shaped, with a smooth continuous border.
D		The maximum diameter is half or more the width of the metaphysis.
E		The epiphysis is as wide as the metaphysis. The central portion of the proximal border has grown toward the end of the middle phalanx, so that the proximal border no longer consists of a single convex surface; no differentiation into palmar and dorsal surfaces, however, can yet be seen.
F		Palmar and dorsal proximal surfaces are distinct, and each has shaped to the trochlear articulation of the middle phalanx. The palmar surface appears as a projection proximal to the thickened white line representing the dorsal surface.

G		The epiphysis caps the methaphysis.
H		Fusion of epiphysis and metaphysis has now begun. (A line is still visible, composed partly of black areas where the epiphyseal cartilage remains and partly of dense white areas where fusion is proceeding.)
I		Fusion of epiphysis and metaphysis is completed. (Over the majority of its length the line of fusion has entirely disappeared, but some thickened remnant of it may still be visible.)

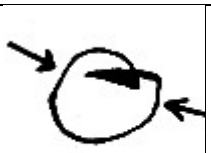
14. **Capitate**		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and oval in shape, with a smooth continuous border.
D		The maximum diameter is half or more the width of the radial metaphysis. The border adjacent to the hamate is now flat or only slightly convex. The border adjacent to the second metacarpal is also beginning to become distinct from the hamate border so that the centre now appears somewhat D-shaped.
E		The hamate border is now concave and slightly thickened. The bone has lengthened, so that the longitudinal diameter is distinctly greater than the transverse, but less than the distance from its proximal border to the radial methaphysis.
F		The longitudinal diameter is now equal to or greater than the distance from its proximal border to the radial metaphysis. (If the hand is improperly posed, with ulnar deviation at the wrist, then this distance is artificially increased. Such a pose should be identified and allowed for.)
G		A thickened white line has appeared along the latero-distal border, due to the formation of the articular facets with the second and third metacarpals. A thickened white line has appeared at the middle of the concavity of the hamate border, due to the formation of the articular facet of the hamate.

H		The articular facets for both the second and third metacarpals have now developed so that both palmar and dorsal surfaces are visible. The thickened white line seen along the border of the bone in the last stage is now placed inside the bone's outer margin, because of the growth of the dorsal surface out beyond it.

15. Hamate		
Score		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and round in shape, with a smooth continuous border.
D		The maximum diameter is half or more the width of the radial metaphysis. The surface that later articulates with the triquetral has flattened so that the appearance of the hamate (like that of the capitate at the same stage) is D-shaped, with the straight side running diagonally to the long axis of the hand.
E		The capitate border has now begun to shape to the hamate articular facet of the capitate. This shaping usually takes the form of a slight bulge appearing about half to two-thirds of the way down the border, with somewhat flattened edges proximal and distal to it. The metacarpal and capitate borders have become differentiated so that the shape has changed from D to a three-sided figure.
F		A concavity is now present in the triquetral border (because of the considerable growth upwards towards the base of the fifth metacarpal since the last stage).
G		The articular facet for the fourth metacarpal has now begun to form and differentiation into palmar and dorsal surfaces can be seen as a thickening running along or inside the distal border of the bone.
H		The hook of the hamate has begun to appear as a white line, to be distinguished from the articular surfaces adjacent to metacarpals four and five, described below. The articulations with the fourth and fifth metacarpals have now progressed so that there are two distinct surfaces at the distal edge of the bone, one running transversely and other, on the medial side, running diagonally to axis of the hand.
I		The hook of the hamate is now completely visible.

16. **Triquetral**		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and round in shape, with a smooth continuous border.
D		The maximum diameter is half or more the width of the ulnar metaphysis. The border adjacent to the hamate has flattened.
E		The bone is elongated in shape with the longitudinal diameter distinctly greater than the transverse. (This is due to growth since the last stage having been relatively greatest at the medio-distal border.)
F		The lunate border has now become flat and distinct and forms an angle of a little over 90 degrees with the hamate border. One or both borders show slight thickening as the articular facets begin to form.
G		Palmar and dorsal surfaces are now visible on the hamate and/or lunate borders so that the white lines seen in the last stage at the borders of the bone are now slightly inside the borders.
H		The broadening, chiefly of the distal half of the bone, since the last stage has caused a concavity to appear in the medial border.

17. **Lunate**		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and oval in shape, with a smooth continuous border.
D		The maximum diameter is half or more the width of the ulnar metaphysis. The distal border of the bone is now thickened.
E		The palmar and dorsal surfaces of the distal part of the bone are now clearly defined with one or the other, or both, projecting distal to the thickened white line which marks their area of confluence. The dorsal surface may project towards the scaphoid but no proper saddle, as in the next stage, is yet formed. There is flattening of the border adjacent to the radius.

F		The distal surface now forms a define saddle for articulation with the capitate, due chiefly to an out-growth of its dorsal part towards the scaphoid. This dorsal part extends out beyond the lateral edge of the palmar (thickened) part of the saddle, but less than half way from the palmar edge to the edge of the scaphoid. The scaphoid and triquetral borders are now flat and slightly thickened.
G		The dorsal surface of the capitate saddle has further enlarged since the last stage and now covers more than half the distance from the palmar edge of the saddle to the scaphoid. There is a definite angle between the scaphoid border (which is still straight) and the radial border.
H		The dorsal Surface of the capitate saddle now extends laterally to touch or overlap the edge of the scaphoid. (Either palmar or dorsal surface, or both, depending on individual shape and positioning, touch or overlap the capitate.) The scaphoid border is now concave.

18. **Scaphoid**		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and round in shape, with a smooth continuous border.
D		The maximum diameter is half or more the width of the ulnar metaphysis.
E		The dorsal surface of the capitate articulation is visible outside the thickened white line, which represents the palmar articular surface.
F		The capitate surface is concave in both its palmar and dorsal aspects. The border adjacent to the trapezium and trapezoid is flat.
G		The bone has grown chiefly in a proximal and medial direction, so that its dorsal surface now extends beyond the thickened white line over towards the lunate and proximal part of the capitate. There is now a distinct border running adjacent to the lunate, its direction such that its capitate end is nearer the midline than its radial-epiphyseal end. The border is as yet in contact with the lunate only at the capitate end.

H		The capitate surface conforms closely to the capitate bone throughout the whole of its extend. The lunate border has changed its direction so that now its radial-epiphyseal end is as near or nearer the midline of the hand than the capitate end. The border is now in contact with the lunate bone over most of its distal portion. Lateral enlargement of the distal portion of the bone and differentiation of the radial styloid articular surface has resulted either in a concavity appearing in the distal part of its lateral border, or in the appearance of a distinct distal head.

19. **Trapezium**		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and round in shape, with a smooth continuous border.
D		The maximum diameter is half or more the width of the first metacarpal metaphysis. There is flattening of the border adjacent to the first metacarpal and/or of the scaphoid border; the distance between these two borders is now distinctly less than the diameter at right-angles to them.
E		Since the last stage, the bone has grown chiefly upwards towards the base of the second metacarpal, so that the gap between the two is less than one-third the maximum diameter of the trapezium.
F		The first metacarpal border is now distinctly concave and slightly thickened at about its central portion. (The concavity is due to growth since the last stage being chiefly in the direction of the lateral edge of the base of the first metacarpal.
G		The distal edge of the bone now overlaps slightly the lateral tip of the base of the second metacarpal. The scaphoid border is now flat and thickened and, in a good film, palmar and dorsal articular surfaces of this border can just be made out in the area beyond the overlapping edge of the trapezoid.
H		There is a newly-appeared straight border forming the distal part of the radial side of the bone; the first metacarpal surface meets this border at a sharp point. The first metacarpal surface conforms to the saddle shape of the epiphysis of the first metacarpal with palmar and dorsal surfaces now differentiated.

I		Since the last stage the radial border has further bulged outward so that is has two distinct portions, the distal facing laterally and proximal facing the radial styloid; this proximal portion is slightly concave, or, sometimes, flat.
20. **Trapezoid**		
Stage		
B		The centre is just visible as a single deposit of calcium, or more rarely as multiple deposits. The border is ill-defined.
C		The centre is distinct in appearance and round in shape, with a smooth continuous border.
D		The maximum diameter is half or more the width of the first metacarpal metaphysis.
E		There is now flattering of the capitate border and/or of the border which lies at right-angles to it and which will eventually articulate with the medial side of the base of the second metacarpal.
F		Thickened white lines have appeared along the capitate and/or medial second metacarpal borders. Differentiation of one but not both of these borders into palmar and dorsal surfaces may have taken place. The distal edge of the bone has grown since the last stage and now forms a rounded peak which will later articulate with the central indentation of the second metacarpal base. Though this pick is part of the future dorsal surface and may appear as such, there is at this stage no very clear differentiation into palmar and dorsal surfaces.
G		The dorsal surface of the articulation with the second metacarpal is now visible distal to the thickened white line which marks the edge of the palmar surface. The dorsal surface of the capitate articulation is also now visible. These dorsal outgrowths have developed so that they overlap, or nearly overlap, the edges of the second metacarpal and capitate.
H		The dorsal proximal border of the bone is concave, although the palmar aspect of this border, which shows as a thickened line, remains straight.

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