DENTAL AGE ESTIMATION OF MALAYSIAN JUVENILES USING POPULATION-SPECIFIC STANDARDS

SAFAR SUMIT BUNYARIT

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ABSTRACT

Dental age (DA) of an individual is estimated by comparing the stage of dental growth against published reference dental surveys. Numerous methods of tooth maturity assessment in age prediction have been described. One method introduced by Demirjian et al. (1973), hereafter known as the original method, and another one improvised by Chaillet & Demirjian (2004), hereafter known as the modified method, are two of those most widely employed as standards. In this retrospective cross-sectional study, both methods were applied to Malaysian juveniles; when the methods were found to be unsuitable, a population-specific method for DA estimation was developed based on formation of the left mandibular permanent teeth.

A total of 4614 dental panoramic tomograms of Malaysian juveniles of known chronological age (CA) comprising 2301 males and 2313 females aged 5-18 years old were examined. The DA was compared with the CA using paired *t*-test. The mean age of an individual tooth for each developmental stage was calculated; the DA was converted using Demirjian's maturity scores. Additionally, the pattern and level of tooth development within dental arches were determined and compared by age, gender and ethnicity.

The dental maturity of Malaysian juveniles was generally overestimated when Demirjian's original method was used. Malay boys and girls were overestimated by 0.36±0.93 and 0.25±0.83 years, Chinese boys and girls by 0.47±0.86 and 0.34±1.01 years, and Indian boys and girls by 0.56±0.97 and 0.43±0.90 years, respectively. In contrast, dental maturity of these juveniles was underestimated when the modified method was applied. Malay boys and girls were underestimated by -2.09±0.90 and -2.79±0.99 years, Chinese boys and girls by -1.92±0.94 and -2.76±1.05 years, and Indian boys and girls by -1.68±1.00 and -2.56±1 years, respectively.

Considering the over- and under-estimation of DA in the respective methods, Demirjian's scores were adapted by using artificial neural networks (ANN) to produce more accurate DA estimation. With the ANN treatment, differences between the CA and DA when compared against Demirjian's original method were statistically insignificant: for Malay boys and girls the differences were 0.05±0.83 and 0.04±0.79 years, for Chinese boys and girls, 0.002±0.78 and 0.028±1.11 years, and for Indian boys and girls, 0.039±0.86 and 0.032±0.93 years, respectively.

Malaysian girls were generally faster than boys in tooth development especially in the first (Q1) and second (Q2) quadrants. The third molar mineralisation was similar between boys and girls, except for difference by one stage. Within dental arches, the third (Q3) and fourth (Q4) quadrants were more developed than Q1 and Q2. The difference between Q1 and Q2 and between Q3 and Q4 were statistically insignificant, whereas the difference between both Q1 and Q2 with Q3 and Q4 were significant for both genders and all ethnicities. Overall, Indians were more advanced compared to the Chinese, who in turn were more advanced than Malays.

In conclusion, both the original and modified methods for DA estimation were inapplicable for Malaysian juveniles. Thus, a population-specific method was developed that improved the accuracy in DA estimation. The improved scores would be useful in clinical and forensic applications in the future.

Keywords: Malaysian juveniles, dental age estimation, artificial neural networks, Demirjian's methods, population-specific standards.

ABSTRAK

Umur pergigian (DA) bagi seseorang individu dianggarkan melalui perbandingan antara tahap pertumbuhan gigi dengan bancian rujukan gigi yang telah diterbitkan. Banyak kaedah penilaian kematangan gigi telah dihuraikan bagi anggaran umur. Satu kaedah yang diperkenalkan oleh Demirjian et al. (1973), dinamakan kaedah asal, dan kaedah yang ditambah baik oleh Chaillet & Demirjian (2004), dinamakan kaedah terubahsuai, adalah dua kaedah yang digunakan secara meluas. Dalam kajian keratan rentas retrospektif ini, kedua-dua kaedah tersebut digunapakai ke atas para juvana Malaysia; tatkala didapati kaedah-kaedah tersebut tidak bertepatan, maka kaedah anggaran DA khusus bagi populasi ini telah dibangunkan berdasarkan pembentukan gigi kekal mandibel kiri.

Sejumlah 4614 tomogram panoramik gigi bagi juvana Malaysia yang diketahui umur kronologi (CA) masing-masing terdiri daripada 2301 kanak-kanak lelaki dan 2313 perempuan berumur 5-18 tahun telah diperiksa. Perbandingan antara DA dan CA dilakukan dengan ujian pasangan t. Umur min setiap gigi bagi setiap tahap perkembangan telah dikira; DA seterusnya ditukar dengan menggunakan skor kematangan Demirjian. Tambahan pula, corak serta tahap perkembangan gigi dalam arca gigi telah ditentukan serta dibandingkan dari segi umur, jantina dan kaum etnik.

Kematangan gigi juvana Malaysia umumnya terlebih anggar secara signifikan apabila kaedah Demirjian asal digunapakai. Kanak-kanak lelaki dan perempuan Melayu terlebih anggar sebanyak 0.36±0.93 dan 0.25±0.83 tahun, kanak-kanak lelaki dan perempuan Cina sebanyak 0.47±0.86 dan 0.34±1.01 tahun, dan kanak-kanak lelaki dan perempuan India sebanyak 0.56±0.97 dan 0.43±0.90 tahun, masing-masing. Sebaliknya, kematangan gigi para juvana ini terkurang anggar apabila kaedah terubahsuai digunapakai. Kanak-kanak lelaki dan perempuan Melayu terkurang anggar sebanyak -2.09±0.90 dan -2.79±0.99 tahun, kanak-kanak lelaki dan perempuan Cina sebanyak -

1.92±0.94 dan -2.76±1.05 tahun, dan kanak-kanak lelaki dan perempuan India sebanyak -1.68±1.00 dan -2.56±1.00, masing-masing.

Mengambil kira kaedah-kaedah yang terlebih dan terkurang anggar ini, skor-skor Demirjian telah diadaptasi dengan menggunakan rangkaian saraf buatan (ANN) untuk menghasilkan anggaran DA yang lebih jitu. Setelah dilaksanakan analisa ANN, perbezaan antara CA dan DA menjadi tidak signifikan: bagi kaedah Demirjian asal, perbezaan bagi kanak-kanak lelaki dan perempuan Melayu adalah masing-masing 0.05±0.83 dan 0.04±0.79 tahun, kanak-kanak lelaki dan perempuan Cina adalah 0.002±0.78 dan 0.028±1.11 tahun, dan kanak-kanak lelaki dan perempuan India adalah 0.039±0.86 dan 0.032±0.93.

Perkembangan gigi kanak-kanak perempuan Malaysia umumnya lebih cepat berbanding lelaki terutama dalam suku pertama (Q1) dan kedua (Q2). Mineralisasi geraham ketiga serupa antara lelaki dan perempuan, dan hanya berbeza sebanyak satu tahap. Perbandinagn kalangan suku arca gigi menunjukkan suku ketiga (Q3) dan keempat (Q4) lebih cepat berkembang berbanding Q1 dan Q2. Perbezaan perkembangan antara Q1 dengan Q2, serta antara Q3 dengan Q4 adalah tidak signifikan, manakala perbezaan antara Q1 dan Q2 dengan Q3 dan Q4 adalah signifikan bagi kedua-dua jantina dan bangsa etnik. Secara umumnya, kanak-kanak India adalah lebih cepat berbanding Cina, dan kanak-kanak Cina lebih cepat berbanding Melayu.

Kesimpulannya, kedua-dua kaedah asal dan terubahsuai Demirjian tidak sesuai digunapakai bagi juvana Malaysia. Maka, satu kaedah khusus yang lebih jitu dalam anggaran DA bagi populasi ini telah dibangunkan. Skor-skor yang lebih jitu ini boleh dimanfaatkan dalam kegunaan klinikal dan forensik pada masa akan datang.

Keywords: Juvana-juvana Malaysia, anggaran umur pergigian, rangkaian saraf buatan, kaedah-kaedah Demirjian, piawaian khusus-populasi.

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3D	:	Three-dimensional
ANN	:	Artificial neural network
BARX-1	:	Homeobox genes
BNPs	:	Brain natriuretic peptides
CA	:	Chronological age
CBCT	:	Cone beam computed tomography
Cbfa1	:	A transcriptional activator of osteoblast differentiation during embryonic development; also expressed in differentiated osteoblasts postnatally.
CC	:	Central canal
CP	:	Central plane
CSF-1	:	Colony-stimulating factor-one
CT	:	Computerized tomography
DA	:	Dental age
DAA	:	Dental age estimation - dental age estimation and assessment
DARLInG	:	Dental Age Research London Information Group
DEA	:	Demirjian Estimated Age
DMP	:	the age of the person is read from the graphs of DMP
DPTs	:	Dental panoramic tomographs
EDA	:	Ethylene diamine
EEE	:	External Enamel epithelium
FDI	:	Fédération Dentaire Internationale
Grade O		Indicated for tooth is missing, extracting, congenital absent
Grade X		Indicated for tooth cannot be graded
Grades 0 and 1	:	Crypt stage
HERS	:	Hertwig’s epithelial root sheath

IEE	:	Internal Enamel epithelium
IL	:	Image layer
IQ	:	Intelligent quotient
M3	:	Third molar
MCP-1	:	Mmonocyte chemotactic protein-1
MIH	:	Molar incisor hypomineralisation
MLP	:	Multilayer or multiple layer perceptron
Msx-1	:	Homeobox genes
OEE	:	Outer enamel epithelium
OEE	:	Outer enamel epithelium
OPG	:	Orthopantomograms
PDL	:	Periodontal ligament
Q1, Q2, Q3 and Q4	:	First to fourth quadrants of jaw
RANKL	:	Enhancement of receptor activator of NFkB ligand
Runx2	:	Osteoblast-specific transcription factor
RUS	:	Combination of radius, ulna metacarpals, and phalanges
SD	:	Standard deviation
TMTs	:	Tooth morphology types
UASC	:	Unaccompanied Asylum Seeking Children
WEA	:	Willem Estimated Age

CHAPTER 1: INTRODUCTION

1.1 Background of the study

Malaysia has been seeing an increase in the inflow of transnational populations with each progressive year. Less than 1% of these noncitizens made up the total population back in 1980, and in contrast, in 2010, this figure has increased to 8.3%. These transnational populations comprise asylum seekers and refugees, expatriates, foreign workers, international students and irregular migrants (Kassim, 2014). In many instances, the legal migrants overstayed. As for the illegal ones, there have been reports of illegal migrants being caught in Malaysian territorial waters, with the numbers increasing yearly. For example, 65 illegal migrants were captured in 2006, whereas in 2013, 1,231 have been captured (Low & Mokhtar, 2017). These irregular immigrants originate from diverse countries such as Indonesia, Philippines, Thailand and Myanmar, without the proper documentations including valid age credentials.

Age estimation becomes crucial when individuals without valid age credentials are involved in immigration or criminal inquiries, especially in cases involving conviction and juvenile rehabilitation. In these situations, there is a pressing need for accuracy in age estimation since most irregular migrants have no valid age documentation (Yusof et al., 2014). The age of a person is more accurately known as the chronological age (CA), which is defined as the amount of time that has passed since the person was born (Karlberg et al., 1976). The Study Group on Forensic Age Diagnostics has suggested guidelines for age estimation in living individuals, based on physical examination, bone development and dental development. In addition, in deceased persons, dental age (DA) estimation is one important criterion that is used (Rai & Kaur, 2013).

CA can be estimated by using a combination of methods, including clinical and radiological observations of the stages of development of teeth, secondary sex characteristics, fusion of hand and wrist, fusion of sterno-clavicular bones, fusion of cranial sutures, changes in the pubic symphysis and anterior iliac crest, changes in cranial size, and the degree of occlusal tooth wear (Chaillet et al., 2004 and Priyadarshini et al., 2015). There are several techniques that are used in DA estimation, but the ones that is considered in this thesis is based on morphological and radiological methods (Priyadarshini et al., 2015). A common method of determining dental age is based on the timing and sequence of tooth formation. Tooth formation proceeds progressively and can be observed radiographically, making it useful for dental age estimation (Smith, 1991). The earliest signs of tooth mineralisation are identified from the appearance of radiopaque spots prior to the calcification of the tooth cusps and crown formation, subsequently leading to root development and closure of the root apex (Demirjian et al., 1973). In this thesis, DA estimation is performed using the extra-oral dental panoramic tomographs (DPTs) based on the assessment of the teeth mineralisation stage. It has been adopted by most investigators for their accessibility and ability to visualize all teeth on a single radiograph with minimal distortion (Bijjaragi et al., 2015). In addition, it is simpler and the least invasive compared to biochemical and histological methods that involve laborious laboratory procedures (Panchbhai, 2011).

Apart from forensics, immigration and criminal-related inquiries, DA information is also useful in clinical dentistry, to assist in diagnosis and treatment planning, particularly in the fields of paediatric and orthodontic dentistry (Maber et al., 2006; Rai & Kaur, 2013; and Koshy & Tandon, 1998).

There are various methods in DA estimation based on tooth development that are adopted by researchers. Demirjian's method is perhaps the most widely used method, as it is simple, practical and clearly defines the stages of tooth development, which results in minimal intra- and inter-observer variability (Olze et al., 2005). Demirjian's method used DPTs for comparing various populations, defining the tooth mineralisation stages and assigning them according to pre-determined scores (Demirjian et al., 1973). Demirjian's scores were originally derived from a French-Canadian population. The original Demirjian's method is a 7-tooth method, whereas the modified Demirjian's method is an 8-tooth method. The 8-tooth method includes the third molar, unlike the earlier 7-tooth method. The value of third molar formation in age estimation is acknowledged, despite the fact that this process is subjected to variability in development, eruption pattern, size, contour, positions and is also associated with a high rate of agenesis (John et al., 2012). Third molar formation is crucial as there are hardly any other feasible methods in the estimation of chronological age between the mid-teens and early twenties. This period is the time when all of the other teeth would have erupted and completed root formation. This is a critical period when age estimation is required, as it differentiates the juvenile from the adult chiefly in matters pertaining to interpretation and judgment of criminal law (Solari & Abramovitch, 2001). There are numerous publications on the application of Demirjian's original (Demirjian et al., 1973) and modified methods (Chaillet & Demirjian, 2004) in different populations. With either the original or the modified method, DA estimation may or may not be suitable for the respective populations. This emphasizes the necessity of population-specific customizations of Demirjian's methods (Bijjaragi et al., 2015).

Ethnicity is a factor for influencing dental maturity, although the identification of one's ethnicity may be subjective (Bolanos et al., 2003) -15. Malaysia comprises diverse ethnicities with a breakdown as follows: Malays (54.1%), Chinese (25.4%), Indians/Pakistani (7.5%), myriad indigenous groups (11.7%) and others (1.3%) (Umer, 2011). Thus it would be useful to investigate the ethnic specific patterns of tooth development, with emphasis on the three major ethnicities, namely Malays, Chinese and Indians, for practical statistical purposes.

To date, insufficient knowledge has been obtained about how a person's ethnic origin can influence tooth mineralisation (Olze et al., 2004). What is clear is that the existing published reference dental survey is not necessarily suitable for the Malaysian populations as far as DA assessment is concerned. This study focuses on DA estimation in Malaysian juveniles. Based on the findings from this study, the construction of a Malaysian specific reference dataset was necessary.

1.2 Rationale of the study

The present study was conducted to carry out age estimation based on the development of the complete human dentition in Malaysians aged 5-18 years old. The study used the 'Demirjian system' (Demirjian et al., 1973) (Thorson & Hagg, 1991; Olze et al., 2004), and the 'Chaillet & Demirjian modified method' (2004) as reference standards. In addition, this study is expected to shed new information on differences in the development of dentition among the ethnic groups in the Malaysian population and as a useful tool for clinical assessment and forensic investigation purposes. The use of Demirjian's dental maturity scores for age estimation on global population groups has been highly debated (Jayaraman et al., 2013). Against this backdrop of using Demirjian's method across different populations, there was naturally a need for population specific scores, since the French-Canadian dataset showed a tendency to overestimate the age of subjects of other populations by up to more than six months (Jayaraman et al., 2013). Demirjian's original dental maturity scores were modified using various statistical methodologies to suit the respective populations.

1.3 Objectives of the study

In general, the aim of this study is to develop population-specific standards for age estimation in Malaysian juveniles.

In detail, this study was set out with the following objectives in view:

a) to establish a database of permanent tooth development in Malaysian juveniles,

b) to develop population specific standards for age estimation in Malaysians, partitioned by ethnicity and gender by using the original Demirjian's method and modified method.

c) to develop population specific standards for age estimation in Malaysians, partitioned by ethnicity and gender by using Artificial Neural Networks (ANN) statistical method, and

d) to determine the pattern of tooth development within dental arches and between age groups, gender and ethnic groups.

CHAPTER 2: LITERATURE REVIEW

2.1 What is age

Age, when it is described without specific stipulation, would usually refer to chronological age. In countries where births are registered routinely and are legally enforced, there is usually no pressing need for age estimation. Nevertheless, there are countries that do not record births in a structured manner; numerous cases thus arise whereby documents are fabricated to support the claim of age. Societies exist where the people are unaware of the need to register the birth of their children. When they are persuaded by various requirements, for example, school attendance, claim in accidents and claim for benefits, their birth dates may become disputed. In addition, when disasters such as flood, landslide and war occur, crucial hardcopy documents including birth certificates are lost and must be made anew. Situations may also arise in which these documents appear to be inconsistent with the physiological stage of the person they represent. Under these conditions, it is imperative to carry out age estimation, i.e. estimate the chronological age of living persons (Schmeling et al., 2001; Schmeling et al., 2008).

Furthermore, there are many situations when the chronological age of a person is not as useful or relevant as some other measures of aging. This is particularly true when medical treatments are to be carried out based on the physical conditions of the patient. If the body function of a patient appears to be weaker than the alleged age, modifications and precautions may have to be adjusted to the treatment. Another case when other measures are to be relied for measuring maturity is when a person is to be challenged with extreme physical demands like physical and mental health. In such cases, chronological age is only a reference point, not a factor to be depended upon. As a consequence, investigations for other measures of maturity are required.

The best reference for the age of a person is of course related to the person directly: physical, physiological, psychological, or social maturities. Physical maturity refers to any one of the bodily tissues: height, weight, waist girdle, hip girdle, etc. Physiological measures are bones, auxiliary and pubic hair, genitals, breast development for women and teeth. Psychological age is usually based on the response of a person towards some specific tasks. And social age measures how a person handles various interpersonal situations.

Physical, psychological and social ages of persons of the same chronological age are usually correlated. Hence any of these parameters can be used to estimate the age of a person. For example, until scientific discoveries provided new methods, height had been used as the gauge for age. However, individuals experience different maturation in biological, skeletal, psychological and social growth due to various factors such as poor diet, physical and mental stresses, injuries and these cause discrepancies that absolute estimation of age becomes less certain using any of these parameters.

In general, all other age measures correlate between each other and also correlates with chronological age. Some correlations are significantly high and some are not. When it is necessary to determine the chronological age of a person, the aim is to get the best possible estimate. Ideally it would be best to have all age estimates available so as to create a profile of the chronological age, thus leading to a definite value. However, in reality it is usually only possible to obtain one or two of the age measures. It is the job of investigators to make the best conclusion based on the data available.

2.2 Importance of age estimation

For many important reasons, it becomes necessary to estimate the actual age of a person. These include cases where there is insufficient documental support for the age. In civil administration, when registration of birth is retrospectively made, for replacement of lost documents, or for adoptions, independent age estimation is usually mandatory. In criminal cases, when considering if specific legislation for minors needs to be applied, the age estimate of the accused becomes important (Feijóo et al., 2012). For a person without a birth certificate, an accurate age estimate will help the person to find out his/her actual age (Thevissen et al., 2009; Unicef, 2011).

The role of age estimation has been highlighted in many forensic investigations that it has now been included as an essential component in forensic medicine studies (Al Qahtani et al., 2010; Schmeling et al., 2004; Ritz-Timme et al., 2003; Takasaki et al., 2003).

Various methods have been presented and tested to estimate the chronological age of young individuals: skeletal maturation, dental age estimation, a combination of dental development and anthropometric measurements and a combination of skeletal and tooth eruption.

Some researchers have estimated chronological ages using a combination of methods involving clinical observations of stage of development in secondary sex characteristics, stage of fusion of hand and wrist, fusion of sternoclavicular bones, changes in pubic symphysis and anterior iliac crest, stages of fusion of cranial sutures, changes in cranial size and occlusal tooth wear (Thevissen et al., 2009; Schmeling et al. 2011).

Physiological age can play a role in defining the stage of maturity of a child. Each tissue/organ undergoes a maturation process and this can be tracked with age. In particular, based on the growth of the teeth, dental age is commonly used to track the chronological age of a person. In general, dental development follows a regular pattern tracking the age as a child grows, except in certain situations. Physical growth including weight, height, and waist girdle often deviates from the chronological age, sometimes by a high margin, but correlates fairly with age based on bone growth that measures the relative stage of bone maturation. The close relation between dental and chronological ages makes the former a preferred measure that is used in forensic dentistry to determine the age or to identify the child (Ogodescu et al., 2011).

Age estimation is an important process in forensic medicine, pediatric endocrinology, archaeology, and clinical dentistry. By measuring dental maturity of a person, researchers can use this as a reliable measure of the age of the subject. In particular, pedodontists and orthodontists use dental age in making diagnosis and planning treatment of dental problems (Tunc & Koyuturk, 2008).

Amongst teeth and bones, both of which develop at predictable stages, teeth has the advantage in that the assessment is noninvasive, unlike bones which need to have some parts extracted for analysis (Demirjian, 1973; Sachan, 2013).

Schmeling et al. (2000) listed the most commonly used procedures to estimate age is in criminal cases. These are physical examinations with anthropometric measurements, radiographic examination of the left hand and radiography showing the stages of dental growth. They also surveyed the techniques used by various researchers to determine age in legal cases. These include:

a. Physical examination including stages of development of the genitals, facial, auxiliary and pubic hair growths, and larynx in male subjects; and breast development, auxiliary and pubic hair growth, genitals and shapes of the hips in female subjects.
b. Bone age in carpus (bones in the wrist between the radius and ulna and the metacarpus).
c. Dental age, consisting of stages of dental eruption and dental maturation; in particular, the third molar maturation.
d. Ossification of the medial clavicular epiphyseal cartilage.

In their survey on criminal proceedings Schmeling et al. (2001) also classified experts for age estimations according to their preferences. For those who performed physical examinations, 15 used body measure, and 16 used sexual maturation. For non-dental radiographic methods, the preferred evidences are hand images (22 experts), shoulder or upper arm (5), collar bone (3), pelvis (2) and 1 each using femur, knee, foot, shoulder blade, paranasal sinuses, and breast bone. For dental experts, 19 used dental status, 17 dental films and 5 plaster casts. There was also an expert using cross section of hair as indicator.

Based on their extensive studies, Schmeling et al. (2011) opined that among forensic methods commonly used in age estimation, physical traits are the least precise assessor of age. Physical features mature at rates varying so widely for subjects of the same age that they cannot be used a standalone measure of age. They can only be used as a support to more reliable measures such as skeletal maturity and tooth development. Similarly, as various external factors cause large variations in the onset and development of sexual maturation, the inferred age using this method must never be the sole determining basis of age estimation. For better precision in legal and forensic investigations, different methods are used by experts for children, adolescents and adults. For younger subject, researchers favour morphological methods and radiological examination of dental and skeletal development. This is in view of the fact that dental and skeletal tissues are in regular, predictable transient growth stages during the young ages. In adults, most of these tissues have reached stability, and so little difference exists between say a 20-year-old and a 25-year-old but not for older adults. The difference between the estimated ages and chronological ages may be rather large (Yekkala et al., 2006; Ritz-Timme et al., 2000; Ball, 2002).

Thus there are various modern methods that are available for age estimation in living subjects which are quite accurate: skeletal growth, with radiological supports of hand-wrist, sternoclavicular joints, and long bones, secondary sex characteristics and tooth development (Mesotten et al., 2002). Based on the evidence, age estimation can be divided into two groups: those which use bone growth, and those relying on tooth development (Chaillet et al., 2004).

For dental age estimation of young adults, the stage of maturation of the third molars is considered most useful. This is usually assessed by using radiological image of the teeth. In general, third molar growth appears to show the most consistent rate of development compared to all other developing teeth, particularly those in the 17 to 21 age group. The root pulp and the periodontal ligament in third molars and skeletal variables can also yield useful information (Thevissen et al., 2012).

2.3 Different age estimation methods

2.3.1 Physiological age

Physiological age, also called biological age, measures the stage of development of the body tissues of a person (Baghdadi, 2013). This consists of those age measures which are specific and which can be observed or measured. They are tissue-specific. The subgroups are detailed below.

2.3.1.1 Skeletal age

Skeletal ages, also called bone ages, are measured by using some of the stages of maturity of the bone structures of a person. Since there are different bone structures which develop separately, researchers choose different parts of skeleton for reference.

The skeletal region providing the best age guide is the left hand and wrist. This is most frequently used for measuring skeletal maturity (Tanner & Whitehouse, 1962).

As the hand-wrist reaches complete maturity at around at the age of 16 years, the ossification stage will be a good indicator of age. This can be measured physically or by using x-ray images. In a longitudinal study on aging, Tanner et al. (1975) measured bone age by examining radiographs of left hands and wrists of children aged 3 to 20 years. They created scores on (i) a combination of radius, ulna metacarpals, and phalanges (RUS) (ii) carpal bones, and (iii) RUS and carpal bones. Their bone scores were based on the scale developed by Tanner (1962).

Other skeletal developments, including epiphysial fusion, amino acid racemization, sternoclavicular bones, pubic symphysis changes, fusion of cranial sutures, cranial size, and stages in secondary sex characteristics, have also been used as age estimators. For adolescents, such estimations may be reliable because the tissues are in known transient stages of maturation for this age group. However, they are less reliable for older age groups because the systems would have already reached maturity (Gunst et al., 2003).

2.3.1.2 Somatic age

Somatic ages are measured either separately based on height, weight, waist or hip, or a combination of all these. Height had traditionally been a yardstick to a person's age, even though variations in height among people of the age had been established. An individual's height is dependent on the bone length, particularly the long bones such as femur, tibia and fibula. Thus height should correlate better with bone lengths and therefore it can be implicated that height is a good measure for age. Weight is relied upon only during the first few years of birth, mainly to ascertain that an infant is growing according to the normal standards. It is seldom used to judge the age of adolescents, except to detect abnormality when sickness or deformity is suspected. It is of course generally true that during childhood, a person grows taller, the weight increases, the waist and hip grow proportionally (Tanner, 1962).

2.3.1.3 Secondary sexual characteristics

Secondary sexual characteristics mainly track the changes in adolescent children. During this period, hormone changes, and tissues gradually change in size and form. These include auxiliary hair (armpit hair, beards and moustache for boys), pubic hair, breast development in girls, and genitals. Tanner (1962) established 5 scales for each of pubic hair for both boys and girls, genitals separately for boys and girls and breast development in girls for children aged 9 to 15 years. At 15 years, all secondary sex characteristics should reach adult stage and subsequently very little visible changes occur to these characteristics. These measures vary widely and could only provide a rough guide as an age measure. They are more used to track the development of a child and to see if there is significant advance or delay in the stages of development.

2.3.1.4 Dental age

Dental age is based on the growth and development of teeth, the formation, the eruption, the size and the change in chemical composition. This will be dealt with in a separate section.

2.3.2 Psychological age

Psychological age uses the response of a person in various tasks which involves experience, logic and emotions. It essentially uses the way a person perceives an experience and how he/she reacts in comparison to the general population (Symons, 1941). The way one feels and acts when faced with a particular incidence to a certain extent reflects chronological age.

2.3.3 Social age

Bengston et al. (1977) defines social age in terms of social roles and habits (Birren and Renner, 1977). Social age reflects an individual's place in the society, usually judged in terms of socioeconomic status, occupation, education, race and sex. Barak & Schiffman (1981) related this to self-perception of a person in terms of his/her age group. They call it subjective age. In fact, they also identify personal age and other-perceived age. Each of these is defined in terms of either perception of oneself, perception of oneself in terms of other, and how a person perceives and is perceived by others.

2.3.4 Functional age

Functional age of a person refers to his/her performance in specific tasks against the standard of the population. This may refer to the health of the heart, which may be in such great condition that its function is comparable to that of a person of much younger age. Another is the lung capacity, measuring the volume of air throughput during breathing as compared to the standard of the same age group. In fact, depending on the interest of a study, the functional age of a person can measure any body function of a person to the standard of a person of a similar chronological age. It is usually a task-related measure (Sharkey, 1987). The change in blood pressures after strenuous exercise, the time taken for recovery from exertion, the length of time to continue in a heavy task and many others are used to gauge the functional age of a person. It is also sex-specific, as men and women are expected to have different capacities (The American Senior Fitness Association, 2010).

2.3.5 Mental age

Mental age is used to measure the mental capacity of a person. This is usually based on a set of comprehensive tests to determine the success of a person in answering well-formulated tasks. The score is then compared to the standard of the same age group. A common way is to convert it into a score called the intelligent quotient, and a person is judged to be above average if his IQ is more than 100, and below otherwise. There are also scores setting the thresholds for high intelligence (genius) and mental incapacity or mentally retarded (Wenger & Poe, 2017).

2.3.6 Image-based human age

Estimation of age automatically via facial image analysis has potential but there are certain challenges that would need to be overcome. This is because aging is due to many factors including the genetic makeup, health, living style, living location, and weather conditions. Males and females may age differently. The current age estimation performance based on existing computer systems is still not good enough for practical use and more effort has to be put in this research direction. Face-image-based age prediction can be viewed as a constrained pattern recognition problem involving two general steps: feature extraction and recognition. There are three main approaches for feature extraction: 1) the anthropometric model based on craniofacial development theory and facial skin wrinkle analysis, 2) the aging pattern subspace method, which models a sequence of individual aging face images by learning a subspace representation; the age of a test face is determined by the projection in the subspace that is used to reconstruct the face image, and 3) the regression method, in which facial features are extracted by the active appearance models that incorporate the shape and appearance information together (Guo et al., 2008).

2.4 General outline of the development of teeth and overall human dentition

2.4.1 Tooth development

2.4.1.1 Definition of tooth development

Teeth are organs that develop in the embryo via a series of interactions between the oral epithelium and neural crest-derived ectomesenchyme of the early jaws. These interactions are initiated by the regional production of signaling molecules in the oral epithelium and transfer of information to the underlying mesenchyme via homeobox gene transcription (Seppala et al., 2006). Tooth development is also known as odontogenesis (Bath-Balogh & Fehrenbach, 2011).

Odontogenesis is characterized by the complex interactions between epithelium and mesenchymal tissues and has three overlapping phases: initiation, morphogenesis and histogenesis. Recent research suggests that the foregut endoderm plays a role in tooth initiation (Berkovitz et al., 2009).

Tooth development starts by the sixth week in-utero. The primary epithelial band of upper and lower jaws is formed from the oral epithelium which thickens and invaginates into the mesenchyme. In the seventh week, the primary epithelial band then divides into two processes which are the vestibular lamina and the dental lamina, located buccally and lingually respectively. The cells of the vestibular lamina rapidly enlarge and then degenerate to form a cleft that becomes the vestibular lamina between the cheek and the tooth-bearing area (Nanci, 2012). By the eighth week, a series of swellings forms on the deep surface of the dental lamina. These epithelial swellings indicate early developing tooth germs (Berkovitz et al., 2009).

Odontogenesis is a process that takes place in many stages in a stepwise fashion for primary and permanent dentitions. It is a continuous process without any clear-cut beginning or end point between the stages (Bath-Balogh & Fehrenbach, 2011; Nanci, 2012). The ectodermal-mesenchymal interactions are formed by the following stages;

both dental papilla and dental follicle are originated from the neural crest cells. This is followed by initiation of the oral epithelium with neural crest cells and inductive signal from enamel knot of internal enamel epithelium (BNPs), resulting in controlled morphogenesis and histogenesis by dental papilla at cup stage. This process is completed by expression of *MSX-1* homeobox genes in the incisor region and *BARX-1* homeobox genes in the molar region (Berkovitz et al., 2011).

2.4.1.2 Stages of tooth development

The stages of tooth development have been described in several ways (**Fig. 2.1**). According to Nanci (2012), odontogenesis proceeds in three stages: formation of the bud, cap and bell stages. These terms describe the morphology of the developing tooth germ but do not describe the significant functional changes that occur during development, such as morphogenesis and histodifferentiation. Seppala et al. (2006) divides odontogenesis into six stages which are the epithelial thickening, bud, early cap, late cap, bell and crown stages. Scully (2002) divides odontogenesis into six stages as well, but in relation to the physiological processes involved, which are the initiation, bud, cap, bell, apposition and maturation stages.

Initiation stage	6-7th week
Bud stage	8th week
Cap stage	9-10th week
Bell stage	

Early bell stage between 11-12th week / 14th week:

Morpho-differentiation

Histo-differentiation

External enamel epithelium

Stellate reticulum

Stratum intermedium

Internal enamel epithelium

Late bell stage 18th week (Appositional stage)

Formation of transitory structures

Enamel Knot

Enamel Cord

Enamel Niche

Maturation stage

Crown stage

Figure 2.1 Stages in tooth development (adapted from: Nanci, 2012; Bath-Balogh & Fehrenbach, 2011; Seppala, 2006 & Scully, 2002).

2.4.1.3 Formation of single and multiple roots

Root formation start after coronal dentine has been completed and tooth starts eruption. Both the stellate reticulum and stratum intermedium collapse at cervical loop so that the External Enamel Epithelium (EEE) and Internal Enamel Epithelium (IEE) lie in contact. Following proliferation, these cells form a two-layered structure called Hertwig's epithelial root sheath (HERS) (Scully, 2002).

Hertwig's epithelial root sheath cells extend around the dental pulp between the dental papilla and the dental follicle until it closes all but the basal portion of the pulp. The rim of this root sheath (epithelial diaphragm), encloses the primary apical foramen (Nanci, 2012). As the inner enamel epithelial cells of the root sheath initiate the differentiation of odontoblasts from ectomesenchymal cells at the periphery of the pulp, facing the root sheath, these cells will form the dentine of the root of the single-rooted tooth (Nanci, 2012). As for the tooth crown formation, the ectodermal HERS cells induce dentine formation by initiating differentiation of odontoblasts and the production of root predentine that gets subsequently mineralised. The root dentine is contiguous with coronal dentine.

Some remnants of HERS persist in periodontal ligament (PDL) as a network of epithelial strand & islands named the cell rest of Malassez. The undifferentiated cell in the dental papilla come into contact with the root dentine and these cells differentiate into cementoblasts (Scully, 2002).

When two extension tongues of epithelium diaphragm are growing toward each other from the collar, a primary apical foramen is converted into secondary apical foramina. When three extensions are formed, three secondary apical foramina arise. Multi-rooted teeth also form in a similar manner (Nanci, 2012).

2.4.1.4 Formation of hard tissues: enamel, dentine and cementum

The next stage is the formation of the two principal hard tissues of the tooth, i.e. dentine and enamel (Nanci, 2012). It is known as the appositional stage. Many inductions occur between the ectodermal inner enamel epithelium (IEE) and the ectomesenchymal tissue of the dental papilla. The cells of the IEE, also known as pre-ameloblasts, become more columnar and tall. The nucleus moves to a central position to be repolarised at the end of the cell farthest from the basement membrane. The cells are now ready to produce enamel matrix. Pre-ameloblasts induce the outer cell of the dental papilla to differentiate into odontoblasts. The odontoblasts then produce a layer of predentine on their side of the basement membrane. The basement membrane then disintegrates, allowing the pre-ameloblasts to come into contact with predentine. The predentine becomes mineralised and induce pre-ameloblasts to produce enamel matrix in a process called amelogenesis. The cells are considered mature ameloblasts at this stage. The enamel matrix is secreted from a conical-shaped tip of each ameloblast (Tomes' process). The odontoblasts move inward starting at the tip of future tooth cusp or cusps laying down predentine as they go. Each odontoblast leaves behind a cellular extension of itself known as an odontoblast process within the dentinal tubule. A layer of predentine is always adjacent to the odontoblasts throughout life when the first layer of enamel matrix has formed. The junction between the dentine and enamel becomes the dentinoenamel junction (DEJ) or amelodentinal junction (Scully, 2002; Bath-Balogh & Fehrenbach, 2011).

The enamel matrix contains 90% tyrosine-rich amelogenin protein and a small amount of enamelin (Scully, 2002). As soon as enamel matrix is produced the predentine becomes mineralised dentine. Once the mineralised tissues of enamel and dentine are formed, the ameloblasts lose the source of nourishment from the dental papilla. The stellate reticulum collapses and the blood vessels outside the outer enamel epithelium (OEE) provide the source of raw materials for enamel formation. Dentine mineralises by fusion of centres of calcification (calcospherites).

Dentine formation is termed dentinogenesis. Cementum develops from the dental follicle and its avascular connective tissue that covers the root of teeth. It is subdivided into a pre-functional stage, which occurs throughout root formation and a functional stage that starts when the tooth is in occlusion. This process continues throughout life.

There are two main forms of cementum with different structural and functional characteristics. Acellular cementum provides only attachment for the tooth. On the other hand, cellular cementum responds to tooth wear and movement and is associated with repair of periodontal tissues (Nanci, 2012).

2.4.1.5 Formation of soft tissue or pulp

The dental pulp develops from the dental papilla. It consists of soft connective tissues which support the dentine. It has four distinctive histological appearances: the odontoblastic zone at its periphery; a cell-free zone of Weil beneath the odontoblasts which is prominent in coronal pulp; a cell-rich zone which is prominent in coronal pulp adjacent to the second zone; and the pulp core, which is characterized by the major blood vessels and nerves of pulp (Nanci, 2012).

2.4.1.6 Formation of supporting tissues or periodontium

Formation of the supporting tissues such as periodontal ligament, gingiva, cementum and alveolar bone occur during formation of root. The supporting tissues of the tooth are formed from the dental follicle include the cells of the periodontal ligament and fiber bundles. As the root sheath fragments, ectomesenchymal cells of the dental follicle penetrate between the epithelial fenestration and become added to the newly formed dentine of the root. The cells differentiate into cementum-forming cells or cementoblasts. These cells converted an organic matrix that becomes mineralised and in which collagen fiber bundles of the periodontal ligament become anchored (Nanci, 2012).

2.4.1.7 Eruption of deciduous and permanent teeth

This process occurs when the crown of the tooth moves from its bony crypt and passes through the mucosa lining of the oral cavity. The enamel of the crown is covered by a layer of ameloblasts and remnants of the other three layers of the enamel organ. The bone overlying the erupting tooth is resorbed, and the crown passes through the connective tissue of the mucosa, which is broken down in advance prior to eruption of tooth. The reduced enamel epithelium and the oral epithelium are fused and formed a solid mass of epithelial cells over the crown of the tooth. The central cells in this mass degenerate, forming an epithelial canal through which the crown of the tooth erupts into the oral cavity. Tooth eruption is thus achieved without exposing the surrounding connective tissue and without hemorrhage. Once the tooth pierces the oral epithelium, the dentogingival junction forms from epithelial cells of the oral epithelium and the reduced enamel epithelium (Nanci, 2012).

The mechanism of eruption is dependent on the correlation between space in the eruption course created by the crown follicle, eruption pressure triggered by innervation in the apical root membrane, and the ability of the periodontal ligament to adapt to eruptive movements (Kjær, 2014).

The regulation of tooth eruption has a molecular basis. Based on studies of knock-out mice, osteopetrotic rodents, injections of putative eruption molecules and cultured dental follicle cells, molecules that play a role in eruption include colony-stimulating factor-one (CSF-1), monocyte chemotactic protein-1 (MCP-1), parathyroidhormone-related proteins, interleukin-1a and osteoblast-specific transcription factor, Cbfa1 (Runx2) (Wise et al., 2002).

2.4.1.8 Chronology of human tooth development and eruption timeline

The average timeline for human tooth development and eruption of primary or deciduous teeth, for which each stage can differ in the duration, with a range from as little as several weeks to several years (**Table 2.1**).

Table 2.1 Timeline for human tooth development and eruption for primary teeth

Maxillary (upper) teeth					
Primary teeth	**Central incisor (A)**	**Lateral incisor (B)**	**Canine (C)**	**First molar (D)**	**Second molar (E)**
Initial calcification	14 (13-16) weeks I.U.	16 (14.75-16.5) weeks I.U.	17 (15-18) weeks I.U.	15.5 (14.5-17) weeks I.U.	19 (16-23.5) weeks I.U.
Crown completed	1.5months	2.5 months	9 months	6 months	11 months
Eruption	7.5 months	9 months	18 months	14 months	24 months
Root completed	1.5 years	2 years	3.25 years	2.5 years	3 years
Sequence of emergence	7 months	8 months	16-20 months	12-16 months	21- 30 months
Mandibular (lower) teeth					
Primary teeth	**Central incisor (A)**	**Lateral incisor (B)**	**Canine (C)**	**First molar (D)**	**Second molar (E)**
Initial calcification	14 (13-16) weeks I.U.	16 (14.75-) weeks I.U.	17 (16-) weeks I.U.	15.5 (14.5-17) weeks I.U.	18 (17-19.5) weeks I.U.
Crown completed	2.5 months	3 months	9 months	5.5months	10 months
Eruption	6 months	7 months	16 months	12 months	20 months
Root completed	1 year	1.5 years	3.25 years	2.5 years	3 years
Sequence of emergence	6.5 months	7 months	16-20 months	12-16 months	21-30 months

Adapted from: Nelson, 2014; Dowsing and Sandler, 2007; Hussin et al., 2007; Nunn et al., 2011; Berkovitz et al., 2009. I.U.: Intra-uterine.

The average timeline for human tooth development and eruption of secondary or permanent teeth for which each stage can differ in the duration, with a range from several months to several years (**Table 2.2**).

Table 2.2 Timeline for human tooth development and eruption for permanent teeth

Maxillary (upper) teeth								
Permanent teeth	**Central incisor (1)**	**Lateral incisor (2)**	**Canine (3)**	**First premolar (4)**	**Second premolar (5)**	**First molar (6)**	**Second molar (7)**	**Third molar (8)**
Initial calcification	3-4 months	10-12 months	4-5 months	1.5-1.75 years	2-2.25 years	At birth	2.5-3 years	7-9 years
Crown completed	4-5 years	4-5 years	6-7 years	5-6 years	6-7 years	2.5-3 years	7-8 years	12-16 years
Eruption	7-8 years	8-9 years	11-12 years	10-11 years	10-12 years	6-7 years	12-13 years	17-21 years
Average eruption	7.5 years	8.5 years	11.5 years	10.5 years	12.5 years	6 years	12.5 years	
Root completed	10 years	11 years	13-15 years	12-13 years	12-14 years	9-10 years	14-16 years	18-25 years
Sequence of emergence	2	3	6	4	5	1	7	8
Mandibular (lower) teeth								
Permanent teeth	**Central incisor (1)**	**Lateral incisor (2)**	**Canine (3)**	**First premolar (4)**	**Second premolar (5)**	**First molar (6)**	**Second molar (7)**	**Third molar (8)**
Initial calcification	3-4 months	3-4 months	4-5 months	1.5-2 years	2.25-2.5 years	At birth	2.5-3 years	8-10 years
Crown completed	4-5 years	4-5 years	6-7 years	5-6 years	6-7 years	2.5-3 years	7-8 years	12-16 years
Eruption	6 years	7-8 years	9-10 years	10-12 years	11-12 years	6-7 years	11-13 years	17-21 years
Average eruption	6.5 years	7.5 years	9.5 years	10.5 years	12.5 years	6 years	12.5 years	
Root completed	9 years	10 years	12-14 years	12-13 years	13-14 years	9-10 years	14-15 years	18-25 years
Sequence of emergence	2	3	5	4	6	1	7	8

Adapted from: Nelson, 2014; Dowsing and Sandler, 2007; Hussin et al., 2007; Nunn et al., 2011; Berkovitz et al., 2009; Nizam et al., 2003.

2.4.1.9 Formation of the nerve and vascular tissues of the tooth

During early development of the tooth, the blood vessel clusters ramify around the tooth germ in the dental follicle. The blood vessels enter the dental papilla during the cap stage and increase in their number, reaching a maximum during the bell stage when matrix deposition begins. The enamel organ is avascular, but a high concentration of vessels in the follicle is present, adjacent to the outer enamel epithelium. The nerve fibers approach the developing tooth during the bud-to-cap stage of development. The target of these nerve fibers is the dental follicle. These nerves ramify and form a plexus around the tooth germ and penetrate the dental papilla or pulp when dentinogenesis begins (Nanci, 2012). Other oral tissues such as the periodontal ligament, gingiva, and tooth pulp have rich vascular supply and dense sensory innervation. Therefore, teeth and supporting tissues are susceptible to tissue injury and inflammation (Fristad, 1997).

2.4.1.10 Abnormalities of the teeth

Teeth can exhibit different types of abnormalities. Abnormalities of tooth eruption and exfoliation include disturbances that occur during teething for example presence of eruption cyst. The cause of failure or delayed eruption may be due to generalized conditions like hereditary gingival fibromatosis and Down syndrome, or localized conditions such as congenital absence of teeth and crowding. Infra occlusion or ankylosed primary molars, ectopic eruption of the upper first permanent molars and premature exfoliation are also considered as abnormalities. This can also happen in tooth number. Anodontia is the complete absence of all teeth. In the general population, hypodontia has a prevalence of 0.1% in primary dentition and 3.5 – 6.5% in secondary dentition. This is highly observed in third molars followed by mandibular second premolars and maxillary lateral incisors. In term of gender, females are more affected compared to males (Cameron & Widmer 2013). Likewise, hyperdontia has a prevalence of 0.3-0.8% in primary dentition and 0.1 – 3.8% in secondary dentition (Shah et al., 2008).

Abnormality of tooth structure is caused by disturbance in the structure of enamel. Examples of abnormalities in structure of teeth are hypoplasia caused by deficient matrix formation, pitting of enamel, hypomineralisation due to disturbance of calcification, chronological hypoplasia which is differentiated from other forms of hypoplasia due to its characteristic presentation of symmetrical, multiple and chronological pattern, fluorosis, molar incisor hypomineralisation (MIH) and amelogenesis imperfecta (Crombie et al., 2008; Arrow, 2008; Visram & McKaig, 2006; Jayam et al., 2014; Shargill & Hutton, 2007).

Abnormality in the structure of dentine includes dentinogenesis imperfecta with a prevalence of 1:8000 due to decrease in vitamin D, rickets and Ehlers-Danlos syndrome. Disturbance in the structure of cementum can lead to hypercementosis as seen in Paget's disease. Abnormality in tooth form has an expected prevalence of 0.1 – 0.2% in the secondary dentition. The types of abnormalities in tooth form are double teeth that occurs as germination or fusion (Ammari et al., 2008), macrodontia with a prevalence of 1% in secondary dentition, microdontia with a prevalence of < 0.5% in primary and 2.5% in secondary dentitions, dens in dente which is commonly seen in the maxillary lateral incisors followed by first and second premolars (Vaidyanathan et al., 2008), dilacerations, Turner tooth and taurodontism (Haskova et al., 2009). Abnormality can also occur in tooth color. Common causes of abnormal tooth color are extrinsic staining, intrinsic staining and enamel opacities (Cameron & Widmer, 2013; Suleiman, 2005). Tooth agenesis may originate from either genetic or environmental factors. Genetically determined hypodontic disorders appear as isolated features or as part of a syndrome. *MSX1*, *PAX9*, and *AXIN2* are involved in nonsyndromic hypodontia, while genes such as *SHH*, *PITX2*, *IRF6*, and *p63* are considered to participate in syndromic genetic disorders, which include tooth agenesis (Matalova et al., 2008).

2.4.1.11 Aging of tooth and supporting structures

Dental hard tissues like enamel become less permeable and more brittle with age. There is no significant difference in the elastic modulus of dentine between older or younger teeth. Yet the rate of secondary dentine formation continues. Obliteration of dentine tubules with calcified material spreads from apex toward the direction of crown with age. Tooth-wear can be regarded as a physiological and age-related phenomenon. Dental pulp increases in fibrosis and decreases in vascularity, resulting in decreased defensive capacities. There is an increase in the formation of secondary dentine and calcification of pulp. The periodontium increases in its fibrous tissue content, but the cellular, vascular and cell turn-over decreases (Mitchell et al., 2009).

2.4.1.12 Molecular and genetic basis of tooth development

Genetics play a role in the regulation of tooth development. The BMP, FGF, SHH and WNT conserved signaling pathways have been shown to mediate the epithelial–mesenchymal interactions during tooth development (Bei, 2009). In addition, inhibitors of these signaling pathways have also been shown to control tooth development. When these inhibitors are absent, abnormally-shaped teeth are formed due to ameloblast or odontoblast differentiation defects and reduced matrix deposition. A myriad of mutations that occur in certain genes are associated with certain anomalies. For instance, the *MSX1* gene (the muscle segment homeobox 1 which encodes for MSX1) is associated with tooth agenesis (Frazier-Bowers & Vora, 2017). In addition, *PAX9*, *EDA*, and *AXIN* are also associated with hypodontia. The *WNT10A* gene is associated with missing premolars; in a biallelic mutation it is further associated with missing molars as well as mandibular central incisors (Arzoo et al., 2014). The role of genetics is not investigated in this study; nonetheless it is also an important factor that determines tooth development.

2.4.2 Dental age assessment

Dental age assessment (DAA) is a measurement that is obtained by comparing the dental growth stage of an individual against reference data based on dental surveys (Nambiar, 1995). Edwin Saundérs was the first to propose using information about dental growth as the tool in measuring age. Saundérs presented a pamphlet entitled "Teeth A Test of Age" to the English Parliament in 1837. The conclusion he derived from results gathered on 1000 children was that dentition gave a more accurate estimation in age compared to other measures such as height (Panchbai, 2011; Shamim, 2006). Dental age estimation uses stage of dental development of a person to estimate his/her age. As stated earlier, this is done by referring to standards obtained from surveys of dental development (Nik-Hussein, 2011; Nambiar, 1995; Parekh, 2011).

Various factors form the bases for dentition-based age determination: appearance of tooth germs, gingival emergence, earliest detectable trace of mineralisation, degree of completion of the unerupted tooth, rate of formation of enamel and formation of the neonatal line, clinical eruption, degree of completion of roots of erupted teeth, degree of resorption of deciduous teeth, attrition of the crown, formation of physiologic secondary dentin and cementum, transparency or density of root dentin, degenerative changes such as dental attrition or periodontal recession or gingival recession, root surface resorption, discoloration and staining of teeth and changes in the chemical composition of teeth, racemization of aspartic acid, quantification of cementum layers or decreasing pulpal space, and dentin sclerosis (Pretty, 2003; Rai & Kaur, 2013).

DAA is primarily used to ascertain if the dental age corresponds to the chronological age of a person which is needed for living persons and for unknown deceased persons for various reasons. DAA is crucial when no reliable documentation is available to ascertain the age of a person. This is needed both in civil matters including registration of birth long after birth, lost registration, or registration of children for adoptions and also in criminal cases, when specific legislation may need to be applied to persons identified as minors. When sentences are to be imposed on the accused, factors to be taken into account will include the age of the victim in case of physical or sexual violations or the accused as a factor in plea for mitigation (Feijóo et al., 2012).

Al-Emran (2008) reported wide uses of dental age to estimate the chronological age when dealing with cases involving children of unknown birth records. He believed that dental growth is not much affected by nutritional and endocrine status. Dental age is also used in most societies for school attendance, social benefit, employment, adoption, political asylum and marriage (Willems, 2001).

Dental age estimation also plays a role in international legal processes. For example, in recent years, the appeal for access of young asylum seekers into United Kingdom who appear to be more than 18 years of age is increasing (Roberts et al., 2008). The authorities decided to assess the age based on dental radiographs. The resulting estimated dental age (DA) of the applicant is taken as the estimate of chronological age (CA). In dentistry itself, age estimation is widely used in clinical diagnosis, preventive procedures, surgical procedures, tooth conservation, and archeological and medico-legal investigations (Nambiar et al., 1995). It is a necessary information for the orthodontist when planning and treating different types of malocclusions in relation to maxillo-facial growth. It also frequently contributes to the process of determining the age of cadavers and in skeletal remains (Demirjian, et al., 1973; Baghdadi, 2013).

In medical treatments for patients whose ages are known, the estimated dental ages will show if there are significant differences between the two ages. This information provides very important guide to doctors in planning treatments. Some researchers report this will also serve as a diagnostic method to detect growth abnormality in children so that proper care can be prescribed (Feijóo et al., 2012).

Rai and Kaur (2013) reported that relevant information for dental age estimation are development of teeth, rate of formation of incremental structures in the tooth crown, changes in the pulpodentinal complex and in chemical composition, the fluorescence of dental hard tissues as well as the epidemiological criteria and dental attrition.

Rai (2007) reported that dental ageing is given high weightage among the researchers in forensic medicine and forensic odontology. It is one of the main factors used to identify persons, and plays important roles in forensic medicine, pediatric endocrinology, archeology and clinical dentistry (Erdem et al., 2013).

The two major features for dental age estimation are the sequence of eruption of teeth, and pattern of tooth development. The stage of tooth eruption had been widely used as reference in the past; it is now less relied upon because eruption is a progressing process. There are periods when no tooth appears from the gum (Erdem et al., 2013). Apart from that, the emergence of teeth happens in only a short period. The time when a tooth erupts in the mouth is basically decided by factors such as crowding of teeth and nutrition. In addition, tooth eruption cannot be used for age estimation between the age of 3 and 6 years as the tooth does not emerge during this period. Neither is it useful for age measure past the age of 13 years of a child. When a person's dental development is complete, tooth eruption does not provide any guide to age (Nik-Hussein, 2011), until 17 years when third molars erupt into the oral cavity.

Measures of dental growth use different techniques to assess the stages of growth. These include morphological and radiological techniques. Morphological techniques use the length of the apical dentin translucent zone for reference. The other criteria include tooth attrition, formation of secondary or tertiary dentin, loss of periodontal tissues, apposition of cementum, and external or internal resorption of root (Bosmansa et al., 2005; Bang & Ramm, 1970; Johanson, 1971; Solheim, 1990; Thevissen et al., 2013)

Radiological methods are based on evaluation of tooth development using X-ray images of teeth. These may be extra-oral or intra-oral radiographs. The assessment is based on the stage of tooth mineralisation, the earliest being occurrence of bony crypt followed by calcification of tooth structure, until closure of the root apex. In longitudinal studies, records of tooth development may be obtained from birth until third molar teeth have completed their growth (Erdem et al., 2013). Tooth eruption is a parameter of development morphology which, unlike tooth mineralisation, can be determined in two ways: clinical examination and/or evaluation of dental radiographs (Ozle et al., 2007).

The stage of calcification is the least susceptible to change over the centuries to environmental influences and is independent of somatic growth so it is currently the most accurate basis of estimating dental age (Nik-Hussein, 2011). To provide a reference for biological, physiological or developmental age, a table or chart of such growth of a general population must first be established. Using this table or chart, the stage of skeletal development of a subject can then be ascertained (Moorees et al., 1963).

The general consensus is that methods based on stages of tooth formation are more accurate in estimating chronological age due to the fact that tooth formation varies only slightly between people in comparison to other somatic measures (Hagg & Matsson, 1985). Using wide-ranging survey results, researchers have constructed dental development charts tracking stages of tooth formation. The parameters for dental development are classified according to their functions. These include developmental, morphological, and biochemical tooth changes. Among the morphological indicators, secondary dentine formation is found to be a good predictor of dental age. This measures the formation of further dentine after the completion of the root development. Tertiary dentine is usually the result of tooth attrition, abrasion action, erosion of root, dental caries. It can also be due to changes in the pulp chamber, either in osmotic pressure or volume. Then there is the factor of normal physiological aging. As a result, the changes in volume of the pulp chamber in intact teeth are commonly used to predict dental age (Star et al., 2011). The change of the chemical composition of teeth could be used to track age as it has been established in studies that racemization of aspartic acid in tooth enamel and dentine appears to be increasing with age. This provides a good bio-chronological tool to measure age (Nambiar, 1995). Research in this direction is ongoing (Helfman & Bada, 1975; Arany et al., 2004; Rai & Kaur, 2013).

DAA that is based on tooth developmental stages have been found to be a reliable method in the determination of age of children of unknown birth date (Peiris et al., 2009). A very common method of DAA based on tooth development stages originated from a database comprising French Canadian children (Demirjian et al., 1973). Demirjian’s method has shown good reproducibility between examiners. The applicability of this previously established database as a standard reference dataset of comparison had been tested on groups of various populations for its universal applicability and comparability. In most cases of said comparisons, overestimation of the dental age has been reported (Jayaraman et al., 2012). Much later, a UK dataset of Caucasians was established and was subsequently tested for accuracy (Robert et al., 2008). The age of the subjects was accurately estimated since the dataset they established belonged to the same population group (Mitchel et al., 2009). The accuracy of the estimated age relied on the close correlation of dental maturity between the various populations (Jayaraman et al., 2012).

Standardization of DAA methods and amassing sufficiently large sample numbers are central to producing reliable ethnic and gender-specific reference standards (Hagg & Matsson, 1985; Rosen & Baumwell, 1981; Mornstad et al., 1994). A meta-analysis of DAA in various populations had been conducted towards that end (Robert et al., 2008). The meta-analysis concludes the 99% confidence interval of a new 'test' subject.

Not all late adolescents and emerging adults would have had their third permanent molar fully matured (Solari & Abramovitch, 2001). Thus, estimating age using other biological indicators may be unsuitable in late adolescents and emerging adults (Nambiar, 1995; Willershausen et al., 2001). In a variation of the original Demirjian's method, the maturity of the third permanent molar could be the only suitable means for estimating age in subjects of unknown birth date for late adolescents and emerging adults (Nambiar, 1995). An interesting phenomenon has been observed in this sense. Girls appeared to reach dental maturity faster than boys when tooth development stages were used in DAA (Rosen & Baumwell, 1981; Anderson et al., 1975; Demirjian & Levesque, 1980). On the other hand, dental maturity appeared to be more advanced in boys when third permanent molar was used for DAA (Solari & Abramovitch., 2001; Kullman et al., 1992; Mincer et al., 1993). Thus, the data has been segregated by gender to be able to be more accurately utilized as a reference (Mitchel et al., 2009).

Incidentally, one or more of the third permanent molars is more frequently absent compared to other types of teeth which is natural. In the treatment of such 'missing data', it is appropriate to provide and use summary data for each of the four third molars. Ideally, the estimated age would be more accurate if both a maxillary and mandibular third molar were assessed together, and with even greater precision if all third permanent molars were present (Nambiar, 1995; Mincer et al., 1993).

2.4.3 Dental radiography/imaging

Several types of dental radiographs are available, differing in terms of the way the dental image is taken, produced and viewed, and the purpose of the radiograph. These different processes are broadly clustered under conventional or digital, and there are those for which the image can be captured either intra- or extra-orally. Each type has its strengths. Radiography is known as tomography if it is a sectional radiograph that produces a three-dimensional image.

Panoramic radiography is a tomographic technique that is usually used to assess a patient prior to wisdom tooth surgery or orthodontic treatment. It is also routinely taken on young children to assess the developing dentition. The overview of the facial structures is obtained at a relatively lower radiation dose compared to other types of radiograph. However, panoramic radiograph may not be very accurate as the movement of the tomograph may introduce distortion and magnification. In contrast, periapical radiography is usually used to view the entire tooth and surrounding structures, in particular to observe apical changes, assess during endodontic treatment and assess non-erupted teeth. In this type of intra-oral imaging, the paralleling technique of radiography is commonly employed in which the most central and parallel rays of the beam are directed to the film and teeth. As a result, precise images are obtained with minimal magnification, foreshortening or elongation. However, multiple full mouth intra-oral radiographs require a larger radiation dose compared to a single panoramic radiography (Whaites, 2007).

Computerised tomography (CT) is also a tomographic technique that is used for three dimensional evaluations of oral structures. A fan-shaped x-ray beam is transmitted from a radiographic tube and the machine moves around the patient during which the detectors record the patient's oral structures based on absorption characteristics. A computer reconstructs the information from these multiple projections to form a clear image. The cone-beam computed tomography (CBCT) is an improved technique that uses lower radiation dose compared to conventional multi-slice CT, while providing a higher resolution image compared to conventional films (White & Pharoah, 2014; Bassed, 2011). Other radiographic techniques are lateral oblique radiographs, cephalometric radiographs, advanced imaging technologies like MRI and ultrasound (Priyadarshini et al., 2015).

2.4.4 Why are teeth important for age estimation?

Various studies have attested to the fact that tooth development is not affected significantly by hormone and nutrition of a person (Anderson et al., 1975). They also showed that that the estimated age based on dental growth is more closely correlated with chronological age than developments of other body parts, such as skeleton, height, and weight (Liliequist & Lundberg, 1971; Anderson et al, 1975; Demirjian et al., 1985). Other studies showed that the maturity stage of third molars closely tracked chronological age for certain age groups (Solari & Abramovitch, 2001).

Studies have found that diseases, drug intake and differences in diet have only minimal effects on the stages of tooth development. This makes teeth an ideal indicator of age. When bodies are decomposed, teeth provide the best indicator for the age of the person. The hard calcified nature of teeth keeps them intact for a long period after death, compared to other parts of the skeleton. Teeth are very resistant to environmental wear and tear, even in severe deteriorating conditions such as extreme cold or heat. In cases when a body is partially destroyed by fire or caustic chemicals, teeth would likely be the only tissues which remain in sufficiently good condition for examination. In addition, teeth are preferred among the body tissues in forensic and archeological investigations (Nambiar, 1995).

Similarly, Boonpitaksathit et al. (2010) reported that teeth development is generally unaffected by hormonal and nutritional factors. Thus people of the same age should show similar stages in their tooth development even if they have different living conditions and living standards. Comparative studies have also shown that dental and chronological age have higher correlation compared to other physiological factors including skeleton, height and weight.

Teeth are preferred in age estimation because they are practically immune to mechanical, chemical or physical disturbances (Star et al., 2011). They are capable of remaining intact even when other bone structures have disintegrated. The resilience of the teeth is due to the fact that enamel layer on the teeth is made of hard calcium hydroxyapatite, which better preserve teeth even after death (Nambiar, 1995). Teeth are preserved long after all other tissues and even bones have disintegrated (Kvaal et al., 1995). Thus, teeth, with the supporting tissues which undergo pre-mortem wear and post-mortem deterioration, provide a reliable source of information in the identification of the deceased (Pretty, 2007; Rai, 2007). Many other researchers have shown that dental parameters give the best age estimate in children because of the low variability in rates of calcification, which are basically determined by genes rather than any factor in the environment (Liversidge et al., 2006).

In addition, unlike bones which normally need to be extracted for age examination, teeth can be inspected directly without surgery (Kvaal et al., 1995). This non-invasive feature makes teeth better suited for age examination in living persons.

2.4.5 Techniques in dental age estimation

It can be seen that the chronological age of individuals is crucial in many legal considerations involving criminal proceedings, civil disputes, and internationally related to asylum applications and adoption processing. In such cases, the age of a person is authenticated using scientifically accepted methodologies, with data obtained from research and current legal requirements (Thevissen et al. 2010; Schmeling et al., 2008).

Choronological age (CA) is the age that is calculated from the period since birth. On the other hand, the dental age (DA) of a person is determined by comparing the dental status to the standard obtained from surveys, constructed from a huge sample of representative population. The predominant technique of dental age estimation uses images of radiographs of teeth to be compared against a set standard. The purpose of this procedure is to locate the best possible estimate, as close as possible to the CA (Nik-Hussein, 2011).

Dental age estimation could be made based on tooth eruption or the stage of tooth development in young children where the teeth are still in the transient stage of development. Most researchers prefer using tooth development as the stages are not generally affected by factors such as malnutrition and diseases. Neither are they influenced by crowded arch as a result of retained deciduous predecessors (Rai & Anand, 2007; Roberts et al., 2008; Townsend & Hammel, 1990).

In adults, teeth would have stabilized with very little significant development. Age estimation for them is generally based on the state of structural changes of teeth (Noorazma et al., 2009).

Various attempts have been made to track dental age using the degree of calcification. These are obtained in radiographic examination of permanent teeth. Essentially, age is calculated from the stage of mineralisation of teeth. These are compared to data reported in former studies. The dental age as obtained by Gustafson and Koch (1974) used the time when teeth erupt in their “tooth development diagram”. Mörnstad et al. (1994) used crown height, apex width, and root length of the teeth instead. In nearly all cases, panoramic radiographs are used for defining the stages. However, Moorrees et al. (1963) preferred perapical radiographs.

There are other methods for dental age assessment using odontogenesis of permanent teeth. They generally use stages of dental growth based on radiographic records. Demirjian et al. (1973) proposed their scoring method, which has gained wide use because of its ease in use and simpler scoring. Their method defines eight stages of tooth development, related to the rate at which the crown and root are calcified (Feijóo et al., 2012).

Demirjian and co-workers (1973) used the panoramic radiographs of the left mandibular teeth because these can be seen more clearly, and the degree of calcification can be determined more accurately. Later it was suggested that using less teeth is viable as this will save time of examination and coding (Al Emran, 2008). This is also more practical as some radiographs do not permit clear pictures of all teeth in the left mandibular quadrant. This method has been well-accepted by many practitioners as the maturity scoring system seem to be suitable for universal application and this has been acknowledged by Demirjian at al., in their later work (Demirjian & Goldstein, 1976).

Investigators of forensic odontology use different methods involving dentition to determine chronological age in humans, both living and deceased (Rai & Kaur, 2013; Willems, 2001). They are separated into four categories. These are clinical or visual, radiological, histological, and physical and chemical methods. The clinical method uses visual observations of the stage of tooth eruption to identify the approximate age. Radiographic method is generally more efficient in identifying the stage of development of dentition, by determining, for example, the calcification status of teeth and root resorption. Histological method requires oral tissue preparation to be examined under microscope. Although tedious, this method is probably as accurate as any other method to determine the stage of dental development, by observing the neonatal line, incremental lines and dentin translucency. Thus, it is particularly accurate in estimation of age at early development stages of dentition and is usually used to detect developmental abnormalities. Lastly, physical and chemical methods can be used to analyse dental hard tissues to provide evidence of alteration in ion levels in teeth, thus yielding age estimate, for example, based on fluorescence of cementum and amino acid racemisation (Shamim et al., 2006).

The term dental age usually refers to age estimation based on development of teeth. However, there are various ways by which a person's dental age is described. The Psychology Dictionary defines it generally as "A measure of childhood dental development based on the number of permanent teeth". Many other researchers have more detailed definitions (Corsini, 1999).

In addition, AlQahtani et al. (2010) developed a comprehensive evidence-based atlas to estimate age using both tooth development and alveolar eruption for human individuals between 28 weeks in utero and 23 years of age. Tooth development was determined according to Moorrees et al. (1963) and eruption was assessed relative to the alveolar bone level. AlQahtani et al.'s results showed that tooth formation was least variable in infancy and most variable after the age of 16 years for the development of the third molar.

2.4.6 Importance of Demirjian's method

To date, the method created by Demirjian et al. (1973) and Demirjian and Goldstein (1976) has established itself as the pre-eminent dental age estimator. In the 1973 report, the age was based on values based on the radiographs of the seven left side teeth of the mandible. This is chosen as they appear to be representative of all the teeth.

Demirjian's innovation is the identification of eight stages of calcification for each tooth. A tooth at each stage is then given a score. The procedure in obtaining the score for each stage is based on the Tanner scale (Tanner et al., 1975) for skeletal age. In addition, Healy and Goldstein (1976) provided an explanation for the calculation.

Demirjian and co-workers carried out extensive studies, using dental panoramic radiographs of 1446 boys and 1482 girls between 2 to 20 years old. A set of reference scores is obtained separately for boys and girls in the range 0 to 100. A percentile table is developed showing the score against the age. To estimate the dental age of a child, each tooth stage in the scale A to H is identified. The scores of the seven teeth are summed to give a score. By comparing this score against the percentile table, the dental age is determined.

Demirjian & Goldstein (1976) developed an updated version of the system to estimate dental age. They added two extra stages for tooth growth. Their sample was extended to 2407 boys and 2349 girls. Again, they created percentile standards separately for boys and girls from 2.5 to 17.0 years old. In addition, scoring systems and percentile standards were created for two different sets of 4 teeth. Comparison is made on the measurements of the three systems and the evidence pointed to the possibility that each of these system (original 7 teeth, first 4-teeth and second 4-teeth) may actually refer to different aspects of dental maturity.

In a study by Sukhia & Fida (2010) involving 380 subjects (147 boys and 233 girls) aged 7 to 17 years, both skeletal and dental ages were evaluated. The skeletal maturity was determined using the stages of cervical vertebral maturation of Baccetti et al. (2005). Dental age was calculated by the Demirjian method. They calculated correlation coefficients between skeletal maturity and chronologic age, and between skeletal maturity and dental age using Spearman rank correlation. The correlation between chronologic and dental age was calculated as Pearson correlation coefficient.

They found significant correlations among all three measures for both sexes. In particular, they discovered mandibular first premolar and skeletal age are highly correlated for both sexes. As a conclusion, they proposed that skeletal maturity may be measured based on tooth development at an early age.

Liversidge (2012) reviewed the dental age estimation of Demirjian et al.'s. They looked at data of boys from published reports, comparing maturity curves and difference to the 50th percentile against chronological age and score. Dental maturity, as well as maturity of individual teeth, was compared in the fastest and slowest maturing groups of boys from the Chaillet database (Chaillet et al., 2004). The author found that maturity curves from published reports by age category were generally similar, with differences being detected at the steepest part of the curve. These were reduced when expressed as score rather than age. Many studies report a higher than expected score for chronological age and the database contained more than expected children with scores above the 97th percentile. They made adjustments to the scores for chronological age from this database containing 4072 boys and 3958 girls aged 2.1-17.9 years. They concluded that the reviewed reports were similar to the database with adjusted maturity curve. They also opined that Demirjian's method of measuring dental age is valid in making estimate for a single child but will be erroneous when used to make group comparisons (Liversidge, 2012).

In a recent meta-analysis drawn from the Dental Age Research London Information Group (DARLInG), which is a dental age reference database of Caucasians, the left upper and lower teeth, including all the four wisdom teeth were assessed using Demirjian's method. The developmental stage of each tooth was considered. The findings revealed that the age of young subjects around different age thresholds was accurately estimated (Chudasama et al., 2012). Other researchers such as Erdem et al. (2013) used software to calculate the dental age in their Turkish children (Demirjian's

(1994: CD-ROM. Norwood, MA: Silver Platter Education). The researcher undergoes a training session by using the tutorials provided in the CD-ROM. Prior to each scoring session, the researcher is calibrated by using the CD-ROM program. Only percentile curves are available for conversion of overall maturity score to dental age in the revised version of the method, thus magnified photographs of the percentile curves were obtained. Data from these percentile curves were initially recorded in separate tables for boys and girls, which then were used for conversion. The mean difference between the DA as determined from the French-Canadian standards and the CA of the child segregated by sex and age is calculated and statistically analysed by using paired t-test (Nykänen et al., 1998).

2.4.7 Studies using seven mandibular teeth

Various other teeth-based methods have been developed to assess age of a person (Lewis & Garn, 1960; Anderson et al. 1975; Gulati et al., 1991). The stages of tooth development (Garn et al., 1962), based on radiographs (Liversidge et al., 2003) has been utilised. Most use dental panoramic tomographs (DPTs) because the image of all the tooth morphology types (TMTs) can be seen in the permanent dentition, including the third molars (Solari & Abramovitch, 2001).

2.4.8 Third molar for age estimation and its importance in determination of juvenile versus adult status

The third molar (M3) is also known as the wisdom tooth. It usually appears between 17 and 21 years. Thevissen et al. (2010) studied third molar developmental data in a comparative study of 16- to 22-year-old subjects from nine countries including Belgium, China, Japan, Korea, Poland, Thailand, Turkey, Saudi Arabia and India. The score was obtained using the scale developed by Gleiser and Hunt (1955), which was modified by Köhler (1994).

One main approach in dental age assessment is the evaluation of the mineralisation status of the third molar (Olze et al., 2004). The stage of dental calcification is believed to be more reliable as a measure of age in young children, in comparison with the emergence of teeth. This is because tooth eruption is influenced by tooth crowding which is not dependent on age and causes restricted tooth space, as well as systemic factors such as poor nutrition (Al-Emran, 2008).

Thus, despite the fact that many methods for age estimation are available, it is still a difficult task to determine the CA of children within the range of 15–24 years of age in relation to third molar development (Gunst et al., 2003). This is mainly because the development of these teeth is affected by other factors, such as premature extraction of primary teeth, or crowding of permanent teeth (Erdem et al., 2013).

Lewis & Senn (2010) believed that the third molars provide the only teeth that are a useful guide to estimate chronological age in forensic studies of subjects around 18 years of age. They carried out a review of the principles, methodology, and population data of the most commonly used dental age estimation technique in the United States of America. Specifically, they studied analyses of various third molar development studies using modified Demirjian's method. They focused on methods analysing the development of third molar to find the mean age, and the range of age when a child has attained 18 years of age. They also calculated the probability that an individual has reached the 18-year threshold based on the stage of third molar development.

Naik et al. (2014) carried out studies on 100 digital orthopantomograms (OPG) of patients aged between 7 and 24 years. The study focused on the development of mandibular right third molar. A software was used to analyse the digital images, and SPSS software was used to statistically analyse the data. They found that the males generally had earlier development of third molars compared to females. Using dental age determined by Demirjian's method, the linear correlation with chronological age was found to be significant. However, their data showed that the correlation was higher in age group above 16 years and lower in age group below 16 years. The authors asserted that Demirijian's method could be used for age estimation for people between 7 and 24 years of age.

Liversidge and Marsden (2010) reported there were only six out of 37 methods of age estimates with bias not significant to zero. Mean absolute difference between DA and CA for these methods ranged from 1.45 to 1.97 years. Standard deviation of bias for all methods was around 2 years, with 95% confidence interval of estimated age at ± 4 years. They concluded that most methods using third molar root formation have significant bias. If the third molar is mature, age 18 years is more than likely attained using root stages of Demirjian and Moorrees.

Radiographic assessment of the degree of third-molar formation is important in adolescents and young adults, because it is the only teeth still in development while other permanent teeth have completed their development in this age group (Cantekin et al., 2012). There have been limited studies concerning how ethnic origins can influence tooth mineralisation. This, however, constitutes a restraint on the reliability of age estimation, and hence on the forensic value of information essential to legal security.

When addressing the medicolegal issue of whether an individual is a juvenile or an adult, that is younger or older than 18 years of age, two conceptually different approaches are presented: firstly, the grade of tooth formation is used to predict the chronological age; that is, if a subject presents with grades A through D, he or she is less likely to be 18 years of age (Mincer et al., 1993). Secondly, the degree of confidence that a subject is indeed 18 years old is used if the root apices are closed (stage H).

Policies that grant asylum seekers and refugees under the age of 18 special treatments such as more protection, better access to health care and education, and the right to a legal guardian compared to those above 18 years old are in place. Minors who have sought asylum on their own may not be detained unless necessary. Unaccompanied Asylum Seeking Children (UASC) may not be deported to their country of origin unless there is an assurance that they will be cared for by an adult upon arrival (Supaat, 2014).

2.4.9 Importance of determining if a girl has reached 16 years of age

Some of the skeletal indicators used for forensic age estimation in children and adolescents are hand-wrist, diaphysis-epiphysis fusion, cervical vertebrae, changes in secondary sex characteristics, and fusion of cranial sutures, all of which have their own advantages and disadvantages (Cantekin et al., 2012).

Mitchell et al (2009) reported that the age of 16 years is an important stage in the life with reference to the British Caucasians in the UK, hence the need for age identification. At this age, individuals were deemed by some quarters to be competent to consent to sexual activity and able to give consent for marriage. However, the authorities in the UK have made a number of requests to assess age of young people where illegal sexual activity is suspected. The 16-year threshold was investigated in the UK because individuals under this age are deemed incompetent to consent to sexual activity. The method employed in the investigation involved assessment of all teeth present in the left maxilla and mandible, and the third permanent molars. For each subject in the study, a new method based on meta-analysis was applied to all teeth that were still developing.

The estimated DA was performed by calculating the average of all the teeth present on the radiograph of each individual as generated by the meta-analysis. For each test subject this was then compared to the gold standard of chronological age (Mitchell et al., 2009).

Several studies have demonstrated that dental maturity is more advanced in girls than in boys (Demirjian & Levesque, 1980). On the other hand, there are other studies that have reported of the converse observation, in that when using the third permanent molar tooth for DAA, dental maturity appeared to be more advanced in boys. Thus, the data has to be segregated by gender (Solari & Abramovitch, 2001).

2.4.10 Accuracy of dental age estimation method

The two main groups of techniques of age estimation based on dental maturation are the atlas technique and the scoring technique (Willems et al., 2002). Most methods use information obtained about dental development visualized on panoramic radiographs or cephalometric radiographs (Chaillet et al., 2004).

Most techniques for dental age estimation in children achieve a rather high degree of accuracy. This is attributed to the fact that many of their teeth are at known developing stages. Except in cases of deformities causing unusual development, it is possible to track the stage when teeth attain a certain level of development. Studies have found the standard deviation to be as low as one to two years in studies on children's dental age. As for adults, with teeth having attained maturity, dental-age estimation relies more on attrition rate and secondary dentine development. On the other hand, the variation in estimated age can be generally quite large. Some studies have reported standard deviations of being as high as 10 years or more (Marshall & Tanner, 1969).

Some researchers propose that atlas approach together with scoring system should be used for age determination of children. For adults, morphological techniques and radiological techniques will be more appropriate (Willems et al., 2001). For third molars, either approach can be applied.

Concerning accuracies of dental age estimation, Willerhausen et al. (2012) proposed various dental age determination methods for children. They casted doubt on some strong claims of accuracies in various studies and warned on the limitation of such procedures. In short, researchers should be diligent when reading summaries of high accuracies and correlations.

2.4.11 Classification of age to assist in age estimation

Shamim et al. (2006) suggested separating age estimation on subjects into three phases. These are a) prenatal, neonatal and early postnatal child, b) children and adolescents, and c) adults.

2.4.11.1 Age estimation in prenatal, neonatal and early postnatal child

To gauge the stage of tooth development before mineralisation occurs, the more accurate method is to perform histological analysis. It is known that two to four months after conception, the deciduous teeth start to mineralise. Histological analysis is probably the only practical approach to detect mineralisation. Studies showed that such approach could identify mineralisation as early as 12 weeks before radiographic evidence can be found.

Another measure is the neonatal line, which indicates "birth of a tooth". This is found in the enamel as well as the dentine of deciduous teeth. It can also be seen in permanent first molars. The incremental line of Von Ebner and contour lines of Owen seen in dentine are measures of dental development. The amount of enamel formation during transition from uterus to birth can be used to estimate age of the pre- and post-term foetus. Some studies use the incremental lines of Retzius to assess teeth development stage. However, the lines are frequently affected by various external factors like metabolic disturbances and so is not a good measure of dental age.

Chemical substances such as tetracyclin, lead, strontium and fluoride which may enter the blood stream of the mother will in turn lead to production of characteristic incremental lines (Shamim et al., 2006).

2.4.11.2 Age estimation in children and adolescents

For children and adolescents, stages of tooth eruption and calcification are good guides to estimate dental age (Willem, 2001). For this purpose, radiographical images showing rates of crown formation and stages of root development are used (Shamim et al., 2006). Some studies assess dental age using mandibular third molars by digitization. So far such methods have not yielded accurate estimates as expected (Wedl & Friedrich, 2004).

Broadly, dental age estimation techniques for children may be classified based on the respective approaches. These are the atlas technique, techniques using score, quantity parameter-based technique generally based on Demirjian's method and its modification, measurement of tooth eruption or visual methods.

The dental age estimations for those approaching adulthood mostly follow the research methodology developed by Demirjian et al. (1973). There are also those who measure dental age based on the stage of permanent tooth eruption (Rai & Kaur, 2013).

Several other techniques are used to estimate dental age in children. In general, since most of the teeth are in developing stages, dental age estimation for this group can achieve high level of accuracies (Gunst et al., 2003). The errors are generally in a small margin. The standard deviation (SD) is usually in the range of 1 to 2 years. This compares favorably against dental age estimations for adults, where the SD can reach as much as 10 years.

2.4.11.3 Age estimation in adults

Age estimation for adults is radically different from those for children. In juveniles, when teeth are in the stage of maturation, dental age is best estimated using the dental status of the child as reference, with charts and tables constructed based on dental growth information of large samples (Nambiar, 1995). Such is not the case for age estimations for adults where tooth development has reached the terminal stage.

Most methods for age estimation in adults track regressive changes of hard tissues such as enamel and soft tissues such as root pulp of the teeth to assess the age.

Gustafson (1950) used rates of tooth attrition, stages of apical migration of periodontal ligament, amount of deposition of secondary dentin, extent of cemental apposition, resorption in teeth root and level of transparency of the root dentin to estimate age. Based on these six changes in the teeth, he constructed a formula for age estimation.

Johanson (1971) made modification to Gustafson's method by using multiple regression analysis. He proposed a formula for age estimation with a lower standard error of 5.16 years.

Researchers may also measure the deposition of secondary dentin as observed in periapical radiographs as an age estimate. The ratios of root pulp diameter/crown diameter, pulp/root length, and pulp/root width are used for reference.

The stage of racemization of aspartic acid in coronal dentine of permanent teeth is another measure to estimate the age of an individual. The theory is based on the fact that L aspartic acid changes into D aspartic acid as a person grows older.

As a person ages, cementum and dentin gradually change colors. These are the consequence of infusion of decomposition products from erythrocytes. They lead to color of the tooth growing darker and having stronger fluorescence intensity. These changes are good guides to estimate dental age.

The age of an adult is reflected in the incremental lines of cementum. This measure is however invasive because the reading can only be obtained from an extracted section of the tooth. It is thus not used for living persons.

Root dentine grows to be translucent as a result of increasing intratubular calcification as one ages. The translucency increases gradually. However, rate of translucency frequently underestimates age of older people. This is due to slowing down of dentinal sclerosis. In addition, any irregular junction between translucent zone and non-translucent zone causes extra difficulties to ascertain the length.

Modifying Gustafson's method, Kashyap and Rao (1990) left out the factors of periodontosis and root resorption in their study. The resulting index values of various other parameters undergoing regressive changes were used to estimate age. Their method improved age estimation, giving an error of ±1.59 years. The Spearman coefficient value they obtained for the variables was significantly high at 0.998. Nevertheless, research of adult dental age estimation using modified Gustafson's method generally showed that the results are more accurate when multiple factors are considered.

The assessment of age using permanent dentition becomes limited when the third molars erupt, usually by 17-21 years of age. Two methods are commonly used in dental age estimation; one based on assessment of volume of teeth, which can be achieved by either using the pulp-to-tooth ratio method by Kvaal or the coronal pulp cavity index, and the other based on development of the third molar, either using the Harris and Nortjé method or the Van Heerden system (Panchbhai, 2011).

2.4.12 Gender difference in age estimation

Mani et al. (2008) showed over-estimation of age in Malays that just preceded the onset of pubertal changes, which may indicate the growth spurt of dental tissues along with the overall maturation factors. The fact that puberty generally sets in earlier in girls may explain the over-estimation of age in girls compared with boys. The authors employed two methods of DA estimation in 7–15-year old Malays, and it was found that Demirjian's method overestimated age by 0.75 and 0.61 years, while Willems' method overestimated the age by 0.55 and 0.41 years in boys and girls, respectively.

Nik-Hussein et al. (2011) reported the comparison between mean Chronological Age (CA) and Demirjian Estimated Age (DEA), and between CA and Willlems Estimated Age (WEA) in their cohort. They found that there was greater accuracy for females than males in various age groups. Within a particular age group, almost all of the developmental stages were seen earlier in females as compared to their male counterparts, thus indicating that females achieved earlier dental maturity than males. Again, this indicated the earlier maturation of other parameters of development in females, such as height, sexual maturation, and skeletal development. Hormonal factors in this case may influence the sex differences in dental development, but the exact influence in tooth development is not yet clear.

In 7-13-year-old Turkish children, an over-estimation of the DA by using Demirjian's method was observed (boys 0.52 - 0.86, girls 0.75 - 0.90, both 0.64 - 0.89) (Kırzıoğlu and Ceyhan, 2012). In addition, in Iranian children aged 6–13 years, Demirjian's method overestimated the age of boys by 0.34 years and girls by 0.25 years. The difference between estimated DA and CA for boys and girls showed that the regression lines had a decreasing trend with age (Bagherpour et al., 2010).

With yet other methods of dental estimation in the determination of children aged 6-13 years old, different results were reported. For instance, the Cameriere method overestimated the mean age for girls by 0.09 year whereas it underestimated by −0.02 year for boys. The Haavikko method underestimated the mean age by −0.29 year for girls and −0.09 year for boys. On the other hand, the Willems method overestimated the mean age by +0.24 year in girls and +0.42 year in boys (Galić et al., 2011). In the same Turkish children, an under-estimation of the DA by using Nolla's and Haavikko's methods was observed (boys 0.53 - 0.95, girls 0.57 - 0.91, both 0.54 - 0.93; boys 0.60 - 0.80, girls 0.56 - 0.81, both 0.58 - 0.80). The authors of the Turkish study concluded that Haavikko's method was more accurate in the DA estimation compared to the other methods (Kırzıoğlu & Ceyhan, 2012).

2.4.13 Ethnic differences

In presenting the 1973 report, the Demirjian team pointed out that the sample for which their scores were obtained was of French Canadian descents. They warned that the maturity scores in their report may not be applied to other populations.

Numerous studies using Demirjian's method and its maturity scale suggested that there are differences in CA as a function of the population studied. In particular, Feijóo et al. (2012) concluded that Demirjian's method should not be generalised to other populations.

Many countries experience immigration issues, both legal and illegal, leading to people of many different ethnicities living together (Bosmans et al., 2005). Situations arise when dental age has to be determined to support the chronological age claims. With such varieties in subjects under investigations, the validity of any single age measure needs to be examined. Many studies have been carried out to assess the suitability of Demirjian's scoring method to people of different ethnic origins, and to suggest modifications suited to the cases.

Ambarkova et al. (2014) used Demirjian's and Willems' methods for DA estimation of children in the Former Yugoslav Republic of Macedonia. Using panoramic radiographs of 966 children (485 girls and 481 boys, aged 6-13 years), they obtained DA scores based on four variants of Demirjian's methods and a Willems' method. Demirjian's methods overestimated dental ages significantly compared to the chronological age ($p<0.001$). They concluded that Willems' method was more accurate for their samples, while Demirjian's methods were less accurate.

Kumar and Gopal (2011) evaluated the suitability of age estimation using Demirjian's 8-tooth method using maturity scores and developed a formula specifically for the Indian subjects. They considered the method successful in predicting the age within an error of just over one year. However, with the inclusion of third molar, the error rates increased for the older individuals.

Maber et al. (2006) determined the accuracy of several methods to analyse tooth formation using radiographs of healthy children treated at a dental teaching hospital. The study population consisted of 946 children (491 boys, 455 girls) aged between 3 years and 16.99 years. The ethnic groups are Bangladeshi and British Caucasian, with a similar number of subjects representing each group. Scores based on Demirjian's method were obtained by examination of panoramic radiographs for seven mandibular teeth. The mean difference (±S.D. in years) between dental and chronological age was calculated for each method and tested using *t*-test. Mean difference was also calculated for the age group 3–13.99 years for Haavikko's method (mean and individual teeth). Results showed that Willems' method was the most accurate among the methods employed.

Willems et al. (2001) attempted to ascertain if Demirjian's dental age method overestimated age in a sample of children in a Belgian Caucasian population. The standard was established using 2116 subjects comprising 1029 boys and 1087 girls using Demirjian's technique. Another set of samples of 355 dental panoramic radiographs was later evaluated as a test of the accuracy of the original method and the adapted method. A signed-rank test was performed to determine the age differences between the estimated dental age and the chronological age. A weighted ANOVA was also performed to adapt the scoring system for the Belgian population. The study confirmed that indeed Demirjian's method overestimated chronological age. Their adapted scoring system succeeded in giving new age scores expressed in years, and their results for this population were more accurate compared to the original method.

Many current studies have reported that dental development rates for different populations follow distinctly different patterns. Following this, many countries established population country-specific dental age estimation standard. Studies also evaluated standards of other countries as applied to their own countries, for example, using French-Canadian standards in a Saudi population (Al-Emran, 2008).

Another study involving children of different ethnic groups in South Africa used the age estimation methods of Moorrees and Demirjian. The outcome of study found that the Moorrees' method produced underestimated ages while the Demirjian's method resulted in over-estimation. As a result, dental age standards were developed separately for each ethnic group. Using these dental age standards, they found better estimates compared to both methods of Moorrees et al. and Demirjian. These studies support the belief that specific dental estimation methods need to be established based on each ethnicity in order to produce dental age assessment of higher accuracies (Baghdadi, 2013).

Noble (1976) also observed that the timing and order of dental growth and mineralisation as well as their patterns of development are strongly influenced by racial and familial factors.

Thevissen et al. (2010) asserted that to arrive at an unbiased dental age assessment, the basis of investigation had to be built on a sample of the same origin as the intended individual. Otherwise, it is necessary to provide scientific assumption to justify the findings. It is also necessary to explain the possible effect on the validity of the age prediction. In addition, we need to be careful to arrive at a conclusion on the estimated age based on samples distinct from the intended study.

There is a demand for accurate age calculation, in particular, DA, in living persons of different ethnic origin. Unless there exists a universal formula for dental age estimation, it is appropriate, indeed necessary, for each country to have its own dental age estimation formula or method to determine dental age with different races and ethnicities (Bosmans et al., 2005).

In general, investigators found Demirjian's method to yield higher accuracies for populations of European backgrounds (Hägg & Matsson, 1985; Nykänen et al., 1998; Nyström et al., 2007). However, recent investigations show that there are ethnic differences in dental age measures which cannot be accounted by Demirjian's method (Davis & Hägg, 1994; Koshy & Tandon, 1998; Liversidge et al., 1999; Frucht et al., 2000; Al-Emran, 2008; Rózylo-Kalinowska et al., 2008; Tunc & Koyuturk, 2008). These reports justify the call for separate reference data when applied to each population (Qudeimat & Behbehani, 2009).

In another recent study, Gilberta et al. (2014) evaluated Demirjian's method to estimate age for a population from Sudbury, Ontario, Canada. Using a sample of 245 panoramic radiographs of boys and girls between 5 and 16 years old belonging to various ancestries, they compared their age estimation using Demirjian's method. They concluded that Demirjian's method underestimated the age for 15- and 16 year-old children, but overestimated for all other age groups.

To date there is little meaningful information about how tooth mineralisation can be influenced by ethnic origin. Unfortunately, this lack of information limits the reliability of any age estimation method. In consequence, all such methods are weakened in their values in legal application (Olze et al., 2004).

Therefore, it is not surprising that Feijóo et al. 2012 reported that Demirjian's method yielded different chronological ages depending on the population studied. They concluded that no results or measurements may be extrapolated to a different population groups.

2.4.14 Age estimation in the multiethnic Malaysian population

In the context of the Malaysian population, with people of different ethnic descendants living together, the consideration of ethnicity in age estimation is very important. Many studies to construct accurate methods and formulae for dental age estimations have been developed (Mani et al., 2008; Nik-Hussein et al., 2011; Nambiar, 1995; Noorazma et al., 2009; Asab et at., 2011; John et al., 2012; Yusof et al., 2014 & 2015; Kumaresan et al., 2014; Cugati et al., 2015). It is generally agreed that dental age estimation formula developed for other countries with different races, ethnicities and lifestyle may not be applicable to Malaysians.

In Malaysia, the dental age estimation has a separate dimension because of its diverse races: Malays, Chinese and Indians in West Malaysia, alongside other numerous minor ethnic groups residing in East Malaysia. This makes it necessary to determine if there is a common standard for all. Studies have been carried out to determine the appropriate methods and formulae either for all or for separate ethnic groups (Mani et al., 2008; Nik-Hussein et al., 2011). When Demirjian's method was applied to populations for DA estimation in Malaysia, the calculated result appeared to overestimate the age. It was generally found that Willems' method gave a closer estimate for dental age for Malaysian children in the range of 5–15 years old (Nik-Hussein et al., 2011).

2.4.14.1 The population of Malaysia

Malaysia consists of two distinct geographical segments separated by the South China Sea; peninsular or West Malaysia and East Malaysia. It is situated in a central position within Southeast Asia, being an extension of the Asia land mass as well as being part of the wider Malay Archipelago (Saw, 2015).

Malaysia's population comprises numerous ethnic groups. People of Austronesian origin known as the Bumiputras make up the majority of the population, which include Malays and assorted indigenous groups. Large Chinese and Indian minorities also exist. In a geographical setting where people of different ethnicities live together, mixed marriages would be a natural consequence.

Currently, the ethnic breakdown in Malaysia is as follows: 68.6% Bumiputras of which about 50% of these are Malays, 23.4% Chinese, 7.0% Indians, and 1% others (Current Population Estimates, Department of Statistics Malaysia, 2016).

Yusof et al. (2014) reported that the influx of irregular migrants from the neighboring countries into Malaysia has increased. Irregular migrants are mostly those who enter the country lawfully, but overstayed. About half of the Indonesians who entered Malaysia under a tourist visa between 1996 and February 2003 overstayed upon the expiry of their visa. When it comes to offenses and punishments, most irregular migrants have no valid age documentation. Thus age estimation plays an important role in conviction and juvenile rehabilitation, with emphasis on particular age groups. A child below 12 years is not liable for certain major offenses such as aggravated assault, murder and robbery. A child below 14 years cannot be employed. The status of majority for both sexes and the legal permissible age for marriage in females is set at 18 years. Sexual relationship before 16 years of age is considered rape, even if the female has consented to the act. Legally, males can marry at the age of 21. According to Malaysian Law Section 2 of the Malaysian Child Act 2001 and Section 82 of the Penal Code, a person under the age of 18 years old is considered a child and has not attained the age of criminal responsibility. Jayaraman et al. (2016) have reported the ages of legal importance vary around the world and the most important among them are the minimum age of criminal responsibility, legal age to consent to have sexual relationships, age of majority, to marry and to consume alcohol.

2.4.14.2 Origin of various minority ethnicities

A small minority of Malaysians do not fit into the broader ethnic groups. A small population exists of people of European and Middle Eastern descent. Europeans and Middle Easterners, who first arrived during the colonial period, assimilated through intermarriage into the Christian and Muslim communities. Most Eurasian Malaysians trace their ancestry to British, Dutch and/or Portuguese colonists, represented by the Kristang community flourishing in Malacca. In addition, there is a Nepali population from the Rana, Chettri, Rai and Gurung clans, majority of who lives in Rawang, Selangor. They were originally brought by the British as bodyguards and security personnel. There are the Filipinos and Burmese minorities. There are a small number of ethnic Vietnamese from Cambodia and Vietnam who settled in Malaysia as Vietnam War refugees. To date, there is no consensus on the ethnic profiling of such children of mixed parentage. Some people choose to be identified according to paternal ethnicity; otherwise the others identify themselves as belonging to the "Others" category for want of better classification. The majority choose to identify as Malay as long as either parent is Malay, mainly due to the legal definition of Bumiputra, which translates to ‘son of the soil’. Children of Chinese–Indian parentage are unofficially known as Chindians and are being increasingly represented especially in urban areas.

2.4.15 Justification on the use of panoramic radiography for age estimation

Radiographic and tomographic images are indispensable for human identification in forensic dentistry. The radiographic method is simpler and cheaper than histological and biochemical methods. The techniques employed have improved with the incorporation of information technology resources (Panchbhai, 2011).

The panoramic and intraoral radiographs are the basic imaging modalities used in dentistry. Often they are the only imaging techniques required for delineation of dental anatomy or pathology. Panoramic radiography produces a single image of the maxilla, mandible, teeth, temporomandibular joints and maxillary sinuses. During the exposure to the X-ray source, the detector rotates synchronously around the patient producing a curved surface tomography. However, these techniques give only a two-dimensional view of complicated three-dimensional (3D) structures (Suomalainen, 2015).

Because of the tomographic nature of the technique, only structures located within the tomographic focal plane are well-delineated and those in front and behind that plane are blurred. This tomographic plane, also known as image layer (IL), is horseshoe-shaped.

Objects located behind the IL will appear wider and objects located in front of it will appear narrower. The central region of the IL is called the central plane (CP) of the image layer. Theoretically only objects located in this plane are depicted sharply and relatively undistorted on the final image. Outside the CP of the IL, the discrepancy between the horizontal and vertical magnification is responsible for the distortion, the latter being smaller. Overlapping of the premolars cannot be avoided in the standard panoramic programme because of the anatomy of the jaws. Distortion and overlapping are the reasons why the horizontal measurements are unreliable on panoramic tomography (Lurie, 2004; Whaites, 2007; Welander et al., 1989).

The age assessment methods are relatively simple and involve the identification of the stage of mineralisation on radiographic images. This is followed by their comparison with the standard stage to estimate the approximate age range (Ciapparelli, 1992; Ranganathan et al., 2008).

Panchbhai (2011) listed several features in the assessment of radiological age determination as follows: jaw bones pre-natally; appearance of tooth germs; earliest detectable trace of mineralisation; mineralisation in the different deciduous teeth during intrauterine life; degree of crown completion; eruption of the crown; degree of root completion of erupted or unerupted teeth; degree of resorption of deciduous teeth; measurement of open apices in teeth; volume of pulp chamber and root canals/formation of physiological secondary dentine; tooth-to-pulp ratio; third molar development and topography; and digitization of the available radiographs for analysis of images to obtain the dental information.

2.4.16 Approaches in dental age estimation

Rai and Kaur (2013) listed the methods which have been adopted by various researchers for dental age estimation in adults based on their respective approaches. These include Gustafson's method (1950), Daliza's method (1962), Bang and Ramm's method (1970), Mapless' method (1978), Lamendin et al.'s method (1992), Solheim's method (1993), Kvaal et al.'s method (1995), Prince and Ubelaker's method (2002), Rai et al.'s methods (2006), Cameriere et al.'s method (2007), Rai's method (2009), Cementum Annulations method, and Johanson's method (1971).

Apart from these, some researchers combine morphological and radiological parameters methods for adult age estimation – known as the Kvaal and Solheim's method (1994). Finally there is the biochemical method of age estimation reported by Ohtani et al. (2003).

For clinicians, it is of critical importance to know the accuracy of age estimation methods before they may adopt them in their practice. This is also the case with researchers as many do not ascertain certain factors in their investigations. For example, many researchers disregard gender differences. Another factor is different age ranges, which when not carefully considered yields results which may be dubious. Another possible error is caused by comparing findings of different populations in studies, yet making conclusions as if they belong to the same population (Hagg & Matsson, 1985).

Adult individuals attain maturity differently, and the variability generally becomes higher as age progresses. For example, the stages of mineralisation of permanent teeth differ between males and females. Nolla (1960) reported that while the stages vary between genders, the degree of variability is similar in both genders at higher ages. Anderson et al. (1976) reported that the gender difference for the mandibular canines is highest compared to other teeth.

2.4.17 Scoring for Demirjian's method

Demirjian et al. (1973) noted that most early investigations used teeth eruption as the measure. They felt that the variations in tooth eruption stages among people of the same age were too big for it to be used as a reference for age. Taking a cue from the skeletal scales of Tanner & Whitehouse (1962), they proposed an 8-stage system (A to H), based on the development of the teeth. For each tooth, depending on their types for example, incisor, canine, bicuspid or molar a score is given at each stage and the scores are gender specific. Based on the evaluation of 1446 boys and 1482 girls aged 3 to 17 years, they produced scores for each stage. For example, in boys, the second molar are given scores of 2.1 for stage A, 3.5 for B, 5.9 for C,10.1 for D, 12.5 for E, 13.2 for F, 13.6 for G and 15.4 for H respectively. On the other hand, because of its early developments, the central incisor gets a score of 0.0 at stage D, 1.9 for E, 4.1 for F, 8.2

for G and 11.8 for H. Using the data of the children in their study, they constructed dental maturity percentile (DMP) graphs separately for boys and girls. Three graphs, each representing the 10^{th}, 50^{th} and 90^{th} percentiles were produced.

To estimate the dental age of a child, Demirjian's team originally took only seven mandibular teeth on the left for consideration. First the stage of growth for each tooth was assessed; the scores were then assigned accordingly and summed up. Based on the sum, called the maturity score, the age of the person was read from the graphs of DMP. The common practice was to use the 50^{th} percentile as the assumed age, and the other two as the range. For easy reference, a conversion table of age of the child based on the maturity was also given for each gender. For example, a maturity score of 50.0 for a boy meant that his dental age was 7.2 years.

Close inspection of the conversion chart shows that for boys, there was generally a sharp increase in maturity scores between 6 to 9 years old, signifying accelerated dental development. For girls, the spurt of growth appeared to be narrower, between 6 and 8. The growth in maturity scores tapered off beyond 11 years for both boys and girls, with the same scores for consecutive ages, for example, score of 99.1 for ages 14.8 and 14.9 for girls.

Compared to the atlas approach of Greulich and Pyle (1959), Demirjian's method was much easier and perceptually convincing. It soon gained wide acceptance and adoption by many researchers. Many researches in the line of Demirjian et al. were carried out and generally supported the original findings.

2.4.18 Advantage of Demirjian's methods

To date, Demirjian's dental age estimation method has become widely accepted in forensics. The general consensus is that Demirjian's standards provide the most efficient classification systems, and thus result in reasonably accurate dental age estimation. Demirjian's method has also been shown to be a simple method, with more reliable standardization, intra- and inter-examiner reliability, and good reproducibility (Stavrianos et al., 2008). Demirjian and Goldstein (1976) established 4 methods of age estimation based on the lower left mandibular dentition; the original 7-tooth technique, the revised 7-tooth system, a 4-tooth method, and an alternate 4-tooth approach. Although all 4 of Demirjian's methods are still in use today, both the 4-tooth systems were less popular (Flood et al., 2011).

Forensic age determination of juveniles (≤ 18.0 years of age) is typically performed using the developing dentition. Many researchers including Demirijan et al. defined eight stages of dental development, based on tooth mineralisation (Flood et al., 2011).

As a scoring system based on the developmental stages of teeth, the predicted dental age using Demirjian's method is relatively accurate. It avoids using the eruption process of teeth which is highly influenced by environmental factors, including discrepancies of space in dental arch, previous history of extraction of deciduous teeth, and tipping or impaction of teeth (Willems et al., 2001).

Demirjian's method is helpful to clinicians who wish to ascertain if the dental maturity of an individual is close to the expected normal standards. It is also used to assess the deviation from chronological age. By providing the scores derived from dental stages and relating them to chronological age, Demirjian's method gives the clinicians a guide to predict intervals of age based on the maturity score (Chaillet et al., 2004).

In addition, odontological methods have also been employed to estimate age. These methods define the stages of mineralisation of teeth observed in radiographs and code them according to fixed scoring criteria. As stated earlier, the most common method for age estimation was published in 1973 by Demirjan, Goldstein and Tanner and subsequently modified by other authors. Indeed, the Demirijan method offers the possibility to calculate a maturity score as a function of age and its 95% confidence interval. The maturity scoring system conversion is valid even when relatively small local samples are used. The scoring system allows for the estimation of an equivalent dental age by comparison for different population (Priyadarshini et al., 2015).

Chaillet et al. (2004) and Cameriere et al. (2006) opinionated that Demirjian's scores are more useful as a reference standard. Researchers who already had information about the real age of the children may use Demirjian's method to detect discrepancy, whether their dental maturity were advanced or delayed. They also indicated that the estimates together with the intervals were calculated only for the maturity scores and the results were not suitable to estimate chronological age.

In another study, Chaillet & Demirjian (2004) used panoramic tomograms to measure dental development of 1031 healthy southern French subjects aged between 2 and 18 years. Demirjian's method was applied to calculate the scores using the original set of seven teeth, and another using eight teeth (including the third molar). The maturity scores were expressed as a function of age. A separate table of maturity score was constructed for each gender, and each was accompanied by a corresponding development graph. Their results showed that with the inclusion of the third molar, the age estimates were better even for age groups up to 18 years.

A meta-analysis of published studies which have employed Demirjian and Willems methods of estimating chronological age had been carried out by Esan, Yengopal & Schepartz (2017). The meta-analysis involved 14,109 children comprising 6,581 males and 7,528 females aged 3–18 years in studies using Demirjian's method, and 10,832 children comprising 5,176 males and 5,656 females aged 4–18 years in studies using Willems' method. A weighted mean difference at 95% confidence interval was used to assess accuracies of the two methods in estimating the chronological age.

The meta-analysis revealed that Willems' method provided more accurate estimation of chronological age in different populations compared to Demirjian's method. Demirjian's method was useful in determining maturity scores but became less accurate when those maturity scores were converted to dental ages in different populations. The authors concluded that to achieve the highest accuracy of age estimation possible, population-specific standards, not a universal standard, need to be employed.

An interesting situation is thus observed here, in which the accuracy of the age estimation using Demirjian's method decreases because of an increase in variation but the reliability of the age prediction is higher than or equal to the methods considering specific population scores. This is because Demirjian's method expansively considers multi-ethnic scores. This observation was reported in an age estimation study of 9577 dental panoramic tomograms of healthy children aged 22–25 years old of different ethnic origins from 8 countries (Chaillet, Nystr¨om & Demirjian, 2005). In the study, Demirjian's seven-tooth method was used for determining dental maturity scores, establishing gender-specific tables of maturity scores and development graphs. The authors found that subjects from Australia, France and Finland were among those with the fastest dental maturity followed by those coming from Belgium and Sweden, with those from French-Canada and Korea coming in third. This effect is thus of interest in forensic applications, when the ethnic origin is unknown.

2.4.19 Weakness of Demirjian's methods

Willems (2001) reported that Demirjian's method frequently overestimated CA. Some researchers believe that the original Demirjian's method is inaccurate because it only used the data from seven permanent mandibular teeth (Davis and Hägg, 1994; Liversidge et al., 1999; Kostara et al., 2000) and excluded the third molar. By disregarding the third molars, Demirjian's method failed to assess accurately a subject's dental age at the 18-year threshold (Boonpitaksathit et al., 2010). Demirjian and his team left out the third molar probably because they did not find representative samples for their study. Another possible factor is that third molars exhibit wide variations in rate of development. Inclusion of third molars can provide additional information for assessment of age in the 16–23-year age group. Some researchers using Demirjian's criteria attempted to add third molar development standard to their original investigation. This would extend up to the age of 18 years (Acharya et al., 2011). As mentioned earlier, Chaillet & Demirjian (2004) included third molars in their study and reported better results.

For children aged between 15 and 24 years old, the third molars are the only developing teeth available for assessment. In contrast, the third molar also varies widely in size, time of formation and eruption. As a consequence, many researchers do not consider the third molars as the ideal tool for age estimation (Gunst et al., 2003).

The fact that only maturity scores were used to calculate the predictive interval of Demirjian's dental maturity percentile curves raised concerns over the accuracy of resulting age estimation. Several authors have proposed replacing the scoring of Demirjian's method by polynomial regression or multiple linear regressions. These should be able to yield the age as a function of score, together with suitable intervals (Chaillet et al., 2004).

Unlike sub-adults, DA estimations provide the smallest errors using age-related tooth developmental variables in younger children. The main reason is that in the younger children, the developmental variables can be observed in multiple tooth types and the results can be combined. However, in sub-adults, only third molar development can be included for estimation. Many researchers prefer the use of the seven lower left permanent teeth to estimate the age of children before the age of 16 years (Ramanan et al., 2012).

In a recent report, the limitations of Demirjian's method were summed up as follows: First, obtaining the required DPTs of young children is difficult, for technical, legal and ethical considerations. Second, it is not applicable for children who have missing teeth, either congenital or acquired. Third, it does not consider presence of any systemic diseases. Fourth, scoring of the tooth developmental stage is subjective. Fifth, it does not give maturity scores for stages 1-4 of first molar, central and lateral incisor (Priyadarshini et al., 2015). In general, this method has shown systematic bias and inaccuracy, rendering it unsuitable for age estimation. Thus, it was suggested that Demirjian's original method should be discontinued for forensic age estimation purposes (Carneiro et al., 2015).

2.4.20 Artificial neural networks

The artificial neural networks (ANN) constitute a group of algorithms that are used to analyse data to gain insights on patterns or trends underlying that data. The data analysis in ANN mimics the function of the human brain very closely. Anatomically, the brain comprises basic unit cells known as neurons. A neuron performs a simple task, such as responding to an input signal. A network of neurons can perform complex tasks, such as speech and image recognition, with speed and accuracy. In the conventional statistical regression analysis, the data is analysed in a sequential manner. As a result, valuable trends or information that is contained within a set of data may go undetected. On the other hand, the ANN is an analytical tool that is designed to handle complex nonlinear relationships. It allows for the complex interconnection of the data, like a biological neural network, to take place. ANN is thus used for deep learning or machine learning, a subset of artificial intelligence. ANN is fast and highly scalable with parallel processing (Livingstone, 2008).

Each neural network in the ANN has three main components: node character, network topology, and learning rules. The node is the ANN equivalent of a neuron. Firstly, the node character determines how the signals are processed by the node, such as the number of inputs and outputs associated with the node, the weight associated with each input and output, and the activation function. Secondly, the network topology determines the ways these nodes are organised and connected. Thirdly, the learning rules determine how the weights are initialised and adjusted (Livingstone, 2008).

Several common ANN types are as follows: a) Multi-layer or multiple layer perceptron (MLP) and radial basis function, b) Hopfield net, and c) Kohonen maps. There are other types, but they are not so common nowadays, for example the single-layer perceptron.

A perceptron is a simple network that could only act as a linear classifier. It classifies input by separating two categories with a straight line. The MLP on the other hand comprises more than one perceptron and because of that it can perform nonlinear functions which are more complex but also more powerful. MLP is the most commonly used neural network; it is a good introduction for researchers/users to the notion of deep learning. The multiple perceptrons are composed of an input layer to receive the signal and an output layer that decides or predict about the input. Between the input and output layers are the hidden layers that fine-tune the MLP model. MLP can be used to estimate continuous functions and classification problems. The MLP is 'trained' using a specific type of algorithm. In the algorithm, the input is first propagated through the network and the output is then calculated. The error between the calculated output and the correct output is then propagated backward from the output to the input to adjust the weights. The aim will always be to minimise errors which is why the MLP model is trained to adjust the weights and biases in a back-and-forth manner. The MLP is an example of a feedforward network (Livingstone, 2008). This study employs the MLP ANN, which can be performed by using SPSS software. The other two main types of ANN mentioned above (Hopfield net and Kohonen maps) are feedback networks and are not considered in this study.

In ANN, a classification problem can be coded into a set of binary outputs of 0 or 1. An example of a classification problem was illustrated by using the tumour treatment scenario (Krogh, 2008). If there are three different treatments for a tumour, it could be crucial to determine the best treatment for that tumour. One output unit would represent one treatment, but all three output units would be connected to the same hidden units. Neural networks have found extensive innovative application in science, medicine and engineering.

In medicine, three categories of application for neural networks have been identified in providing crucial medical decision support. Firstly, it is increasingly becoming useful as a tool for attention focusing, allowing for the detection of otherwise untraceable abnormalities if it were to solely depend on human capabilities, in hospital-based information systems and clinical laboratory systems. Secondly, it allows for patient-specific assessment and advice as it is capable of highly accurate diagnostic and prognostic inferences. Finally, it is utilised as an interactive tool for the clinician to gain new insights by hypothetical testing of a patient's condition and effect of different treatment choices (Lisboa, 2002; Livingstone, 2008). In more specific fields of medical research, such as forensics, ANN had been successfully applied in modeling the age at death based on pubic symphysis scores (Corsini et al., 2005). In dentistry, ANN was used in classification of proximal dental caries (Devito et al., 2008), prediction of whether an orthodontic treatment requires extraction (Xie et al., 2010), and prediction of the size of unerupted canines and premolars (Moghimi et al., 2011).

As far as dental age estimation is concerned, a published article back in 2000 had employed the neural network system for dental age evaluation (Ozaki and

Motokawa, 2000). The authors performed dental age evaluation based on tooth eruption status, rather than the tooth mineralisation method employed in our current study. The dental age was evaluated based on a recognition pattern that imitated the pediatric dentist. The neural network was ‘taught’ or ‘trained’ to recognise dental age by using a classic back-propagation learning algorithm (**Fig. 2.2**). Inputs for the neural network model were the 14-tooth eruption status based on Ozaki (2017), each tooth being represented by a scale from -1.0 (pre-eruption) to 1.0 (post-complete eruption) and the output was the dental age. The input patterns were repeatedly fed into the model until the newest set of offset values and weights of the calculated output patterns converged at the node. In their study, the neural network consisted of three layers with three sigmoida1 nodes in the hidden layer and a sigmoid output unit. The procedure was repeated for al1 input-output pairs of the set for 10000 epochs. The total error was calculated using the root mean squared error cost function which is just one of the ways to measure error. The neural network system worked very well with very large datasets.

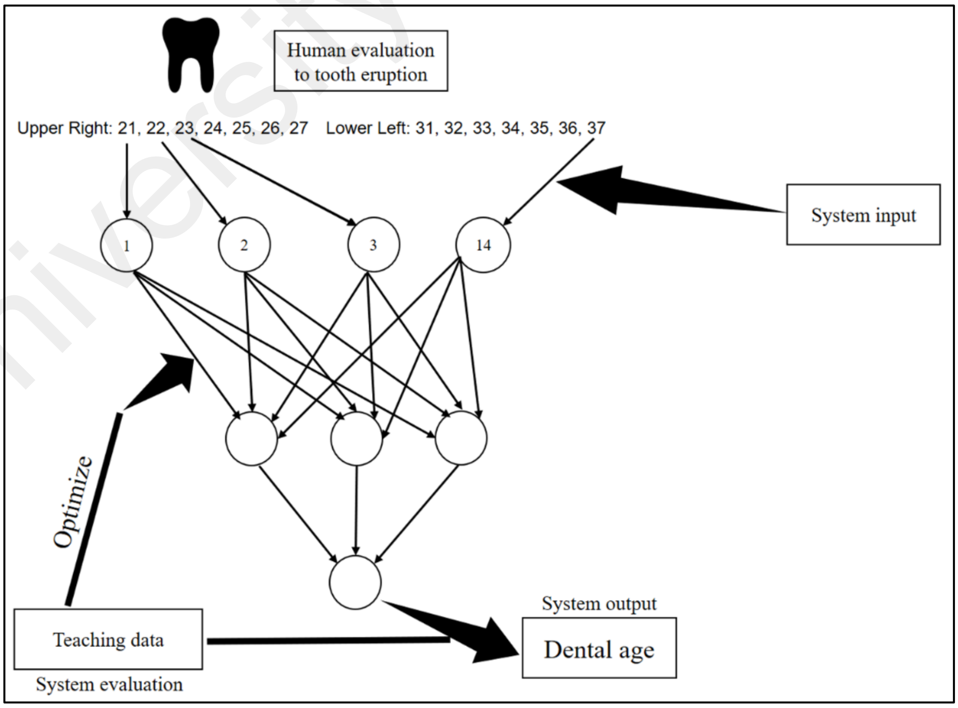

Figure 2.2 Neural network system model for dental age evaluation.
(Adapted from Ozaki and Motokawa, 2000).

An important caveat of ANN is that good practice in model design should be adhered to whenever neural networks is to be considered as a method of data analysis. This is to avoid employing ANN just for the sake of using it, and to avoid overfitting whereby the model perfectly fits only our own dataset but does not fit new incoming data. There are six standard tools as summarised by Lisboa (2002).

Firstly, network regularisation, which refers to any modification that is made to a learning algorithm to reduce its generalisation error but not its training error. Generalisation is when the algorithm is used, it will perform well not just on training data but also on new inputs. Most of the earlier applications of neural networks (first generation) were generalised based on a parsimonious design with few hidden nodes and stopped early by reference to a test dataset to prevent overtraining (Caruana, Lawrence & Giles, 2001). The downside to this simplified version is that the accuracy is compromised. Later applications (third generation neural networks) which employed better regularisation technique showed higher accuracy compared to earlier generation applications.

Secondly, variable selection should be performed carefully. Neural networks benefit analysis of data in which the predictor variables may have non-linear interactions. A detailed interpretation of the relationship between the covariates and the model predictions should also be in place.

Thirdly, validation through support for learned intermediaries. A legal doctrine that applies to the use of decision support systems in medicine is the doctrine of learned intermediaries (Braham & Wyatt, 1989). Clinicians should understand the operation of the system well enough to be able to be accountable for any consequences arising from their medical decision based on ANN.

Fourthly, benchmarking in which this relatively new technology should be demonstrated to perform at least as well as an alternative certified method, if not better.

Fifthly, robustness in performance evaluation. The sources of uncertainty that reduce the performance of the model from one cohort to another include within-patient variation, between-patient variation, case mix differences, instrumentation differences and protocol differences between clinical centres. Three levels of validation to be noted are 1) internal validation, whereby the test sample is used to train and fine-tune the model's parameters, but new data are used to validate performance; 2) temporal validation, whereby data is collected later from the same clinical centre and fed into the model; and 3) external validation, whereby the data was collected from other clinical centres not involved in the model design.

Lastly, comparative trials. These are designed to assess the changes to expert intervention with and without access to a decision support system (Hunt et al., 1998; Othmann et al., 1999).

Thus, the standards listed above should merit careful consideration whenever a researcher wishes to apply such a powerful analytical method as ANN. The role of computers in artificial intelligence in the broad field of medicine and dentistry is now being pushed and the sky's the limit in terms of potential applications in the future.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study design

This is a retrospective cross-sectional study based on dental records of male and female patients of known ages, treated at the Faculty of Dentistry, University of Malaya, Kuala Lumpur, Malaysia. Data on ethnicity and any medical and/or dental anomalies were collected. The dental records used for this study were dated from January 2001 to December 2014.

3.2 Ethical approval

Institutional and ethical approval has been obtained from the University of Malaya Medical Ethics Committee, Faculty of Dentistry [Reference No. DFOP0801/0003(P)] in order to gain access to the dental panoramic tomograms (DPTs) filed along with the dental records of the patients.

3.3 Sample selection

3.3.1 Classification of subjects

The subjects to be analysed are in the age group 5 years (5 years 0 months to 5 years 12 months) to 18 years (18 years 0 months to 18 years 12 months) and subdivided into categories of male and female. The subjects were also divided based on ethnicity into Malays, Chinese and Indians.

3.3.2 Selection criteria

Dental panoramic tomograms of subjects of good quality and showing no obvious developmental pathology were selected. The subject must have at least one of the four third molars, at varying stages of development (Gunst et al., 2003). For the purpose of integrity of data used, the following groups of DPTs were excluded: Poorly-taken or blurred panoramic radiographs and those without the complete accompanying patient records, DPTs that show more missing or abnormal teeth, radiographs that show evidence of systemic or metabolic diseases, fractures, cysts and neoplasms which may affect tooth development, and subjects undergoing orthodontic treatment.

3.4 Material used for assessment

3.4.1 Dental panoramic tomograms

Digital images were obtained by using various dental panoramic machines available in the dental faculty: the Orthopantomograph OP 100D® (Instrumentarium Imaging, Tuusula, Finland), with a variable anode voltage of 64 – 66kV and an anodic current of 8.0 mA, and exposure time of 15 – 18 seconds with a magnification factor of 1.25; the Kodak 9000 Extra-oral Imaging System® (Eastman Kodak Co, Rochester, NY, USA), with a variable anode voltage of 64 – 66 kV and an anodic current of 8 – 10 mA, and exposure time of 13.5 – 14.3 seconds with a magnification factor of 1.25; and the Veraviewepocs 2D® (Morita, Tokyo, Japan) with a variable anode voltage of 64 – 66 kV and an anodic current of 5.9 – 7.6 mA, and exposure time of 14.8 seconds with a magnification factor of 1.25. As all these machines were digital machines, panoramic films were printed using Fuji films (Fuji Film DRYPIX 4000®, Tokyo, Japan). Some of the earlier DPT radiographs were taken using different machines, developed in the dark room, and were thus only available in hardcopy film format. The newer ones were recorded in the digital format and stored in the Faculty of Dentistry server.

3.4.2 In-house dental age chart

The stages were recorded in a chart which was slightly modified after Demirjian (1973) to record demographics of subjects (**Fig. 3.1**). The chart included the name of the patient, registration number, race, sex, age, date of birth and the date the radiographs were taken. It also included the schematic drawings of Demirjian et al. (1973) developmental stages A – H for all teeth, for quadrants Q1, Q2, Q3 and Q4. Two more grades were added: grade O if the tooth is not developed or missing, and grade X when the tooth could not be graded when its image was blurred because it was not in the image layer or focal trough.

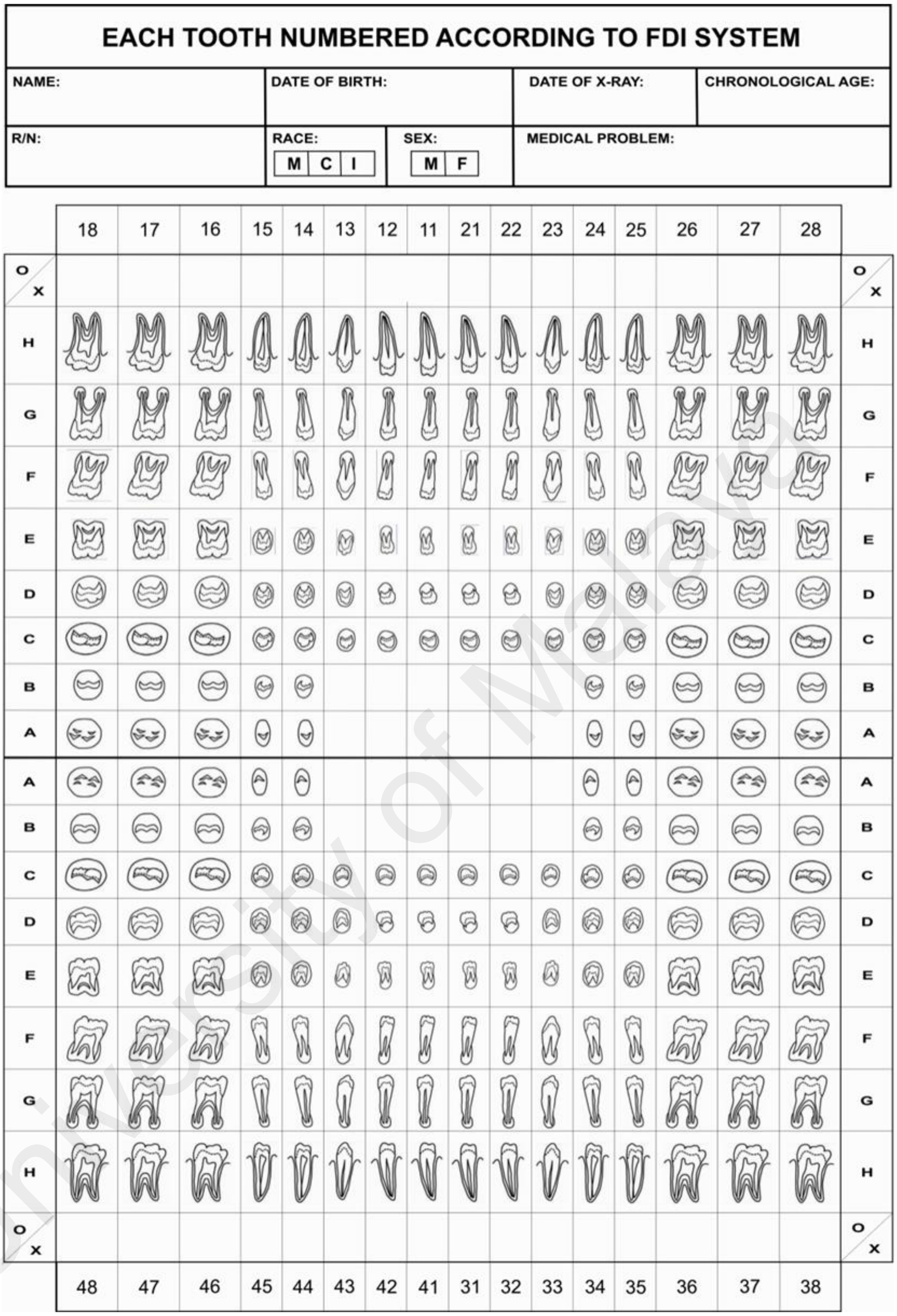

Figure 3.1 Dental age record chart (according to Demirjian et al., 1973).

3.5 Assessment of panoramic radiographs

3.5.1 Assessment of dental panoramic tomograms

For each DPT hard copy film, the DPT was positioned on an x-ray viewer and the developmental stages of teeth seen in the radiographs were viewed using the illuminator (Microsaintific SDN BHD) with the aid of a magnifying lens. All DPT images were captured and stored as JPG files of 2.1 MB each without compression. The images were copied and transferred into a compact disc. The assessments were performed using Windows Photo Viewer or Microsoft Office Picture Manager Software for PC using a PC monitor 18" flat screen (Dell OptiPlex 7010™). These programs enabled enlargement and controlled the brightness and contrast of the image for assessments when necessary.

3.5.2 Nomenclature for teeth

The tooth notation that was used was based on a two-digit system as proposed by Fédération Dentaire Internationale (FDI) for both the primary and permanent dentitions which has been adopted by the World Health Organization and accepted by other organizations such as the Interpol and International Association for Dental Research. The FDI system of tooth notation for permanent teeth is as follows:

i. Upper Right: 18, 17, 16, 15, 14, 13, 12, 11
ii. Upper Left: 21, 22, 23, 24, 25, 26, 27, 28
iii. Lower Right: 48, 47, 46, 45, 44, 43, 42, 41
iv. Lower Left: 31, 32, 33, 34, 35, 36, 37, 38

3.6 Methods used in dental age estimation in this study

Two methods were used to estimate dental age in this study, forensic and mineralisation.

3.6.1 Forensic method

The forensic method is further divided into two, as follows:

a. The 7-tooth method after Demirjian et al. (1973) for 5–16-year-old children, which is also known as the original method. This part of the study provided the mean age of each tooth developmental stage, with a sample size of 2950 subjects. The teeth were numbered in accordance with the FDI system.
b. The 8-tooth method of Chaillet and Demirjian (2004) for 5–18-year-old children, which is also known as the modified method. This part of the study provided the mean age of each tooth developmental stage, with a sample size of 3812 subjects. Similarly, the teeth were numbered in accordance with the FDI system.

3.6.1.1 The original Demirjian dental age assessment method 1973

Based on the method of Demirjian *et al*. (1973), the eight stages of mineralisation for each tooth was identified, beginning from the calcification of the tip of a cusp denoted as stage A to the closure of the apex denoted as stage H (**Fig. 3.2**). Seven teeth were evaluated. The stages of mineralisation for each tooth are defined as follows:

A: Cusp tips are mineralised but have not yet coalesced.

B: Mineralised cusps are united so the mature coronal morphology is well defined.

C: The crown is about half formed; the pulp chamber is evident and dentinal deposition is evident.

D:	Crown formation is complete to the dentinoenamel junction. The pulp has a trapezoidal form.

E:	Formation of the inter-radicular bifurcation has begun. Root length is less than the crown length.

F:	Root length is at least as great as crown length and has funnel-shaped endings.

G:	Root walls are parallel, but apices remain open.

H:	Apical ends of the roots are completely closed, and the periodontal membrane has a uniform width around the root.

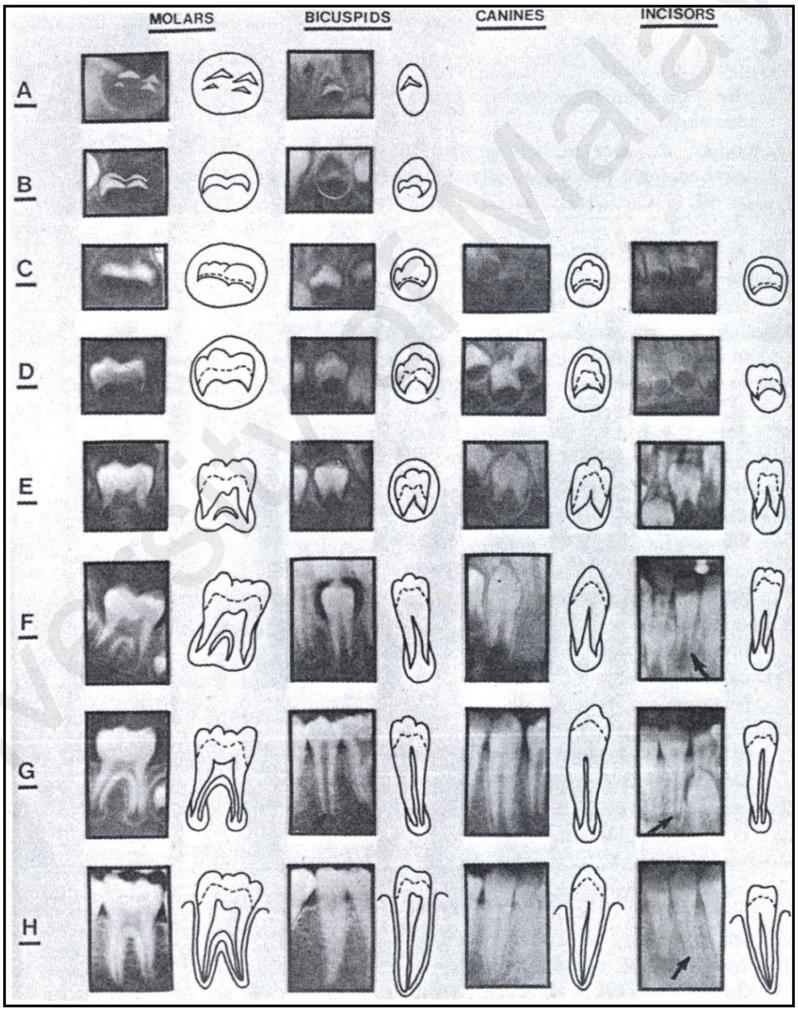

Figure 3.2 Developmental stages of the permanent dentition. (Reproduced from Demirjian et al., 1973).

Specific weighted scores of 7 teeth were summed up as maturity scores or as a function of age with the original Demirjian's method. Maturity scores were then converted into dental age based on dental maturity score per age according to separate tables for boys and girls.

A prediction model for Demirjian's score was established by using Artificial Neural Networks (ANN) analysis, which is elaborated in detail in the later section.

3.6.1.2 The modified Chaillet & Demirjian's dental age estimation method 2004

In this 8-tooth evaluation, Chaillet and Demirjian's method was employed with some modification. In their original method, 10 stages were used, namely the Stages A-H and Stages 0 and 1 (crypt stage). In this study, 10 of the stages were used to identify the eight stages of tooth mineralisation, beginning from the calcification of the tip of a cusp denoted as grade A to the closure of the apex denoted as grade H, as well as missing tooth denoted O (Stage 9) and tooth which cannot be graded denoted as X (**Fig. 3.2**). The 8-tooth method employed eight developmental stages instead of ten. The crypt stage is when the bone crypt can be observed but there is no dental germ inside it. In addition, the weighted score for Stage 0 was only available for third molars in girls, and in second and third molars in boys. On the other hand, the weighted score for Stage 1 was available for third and second molars in girls, and in second and third molars and second premolars in boys (Chaillet and Demirjian, 2004).

Specific weighted scores of 8 teeth were summed up as maturity scores or as a function of age with Chaillet & Demirjian's method, followed by conversion of maturity scores into dental age based on dental maturity score per age, presented in separate tables for boys and girls.

As with the original method, a prediction model for Chaillet & Demirjian's score was established by using ANN, specifically the multilayer perceptron function (Corsini et al., 2005). In this multilayer perceptron function, CA was placed in the 'Covariate' box and Chaillet & Demirjian's score in the 'Dependent variable' box. The result of this analysis was saved as a predicted value (model), which was exported to an XML (extensible markup language) file. This prediction model was applied to obtain a new adapted score, which was converted to the new dental age (NDA). The tables of dental maturity scores were constructed for each gender separately. Prediction of mineralisation stages of already developed teeth was also included in this analysis (Qudeimat & Behbehani, 2009).

3.6.2 Mineralisation method

This second part of the study examined the odontogenesis method in which stages of tooth development were compared in the 4 quadrants of dental arches in the three ethnic groups of both genders. The information and insight into the time of development of permanent teeth has importance in clinical medicine; for instance in pediatrics, it can be used as an indicator of maturity or for showing improvement or side effect of a specific therapy (Bagattoni et al., 2014; Cavric et al., 2016). It is most commonly used to compare with other biological systems of the human body in relation to legal matters and criminal investigations when the birth date of the individual is unknown (Cunha et al., 2009).

A total of 4614 DPTs of healthy children were analysed, comprising Malay, Chinese and Indian subjects, who were further subdivided into 13 age categories (5-18 years) and gender. The determination of the stages of tooth development was carried out based on the digital DPT as well as the hard copy DPT films. Patients aged 5–18 years old with DPTs were identified from the Division of Oral and Maxillofacial Radiology record books. The patient’s folders were retrieved. Details such as date of birth, date radiograph taken, name, sex, age, nationality, medical history and race were confirmed and recorded in the dental chart accordingly. Next, the patients’ digital DPTs were retrieved from the computer hard disk. The dental chart was completed based on the patients' digital DPTs in which the stages of tooth development were recorded. The data from the dental charts were subsequently entered into SPSS for data analysis.

The permanent teeth were evaluated by the classification system described by Demirjian et al. (1973) in eight stages (A – H) were used in describing the formation of the left mandibular permanent teeth for both 7-tooth and 8-tooth methods. Mean and standard deviation were calculated separately for each stage of individual teeth in three ethnic groups and both genders.

In addition, the permanent teeth were also evaluated by the classification system described by Demirjian et al. (1973) in eight stages (A – H) by comparing the 4 quadrants of dental arches in the three ethnic groups of both genders. After the assessment of the developmental stages, the median was identified from the minimum to the maximum stages for each stage and for each tooth. To find the median value, the mineralisation stages were first determined according to their rating for each tooth, after which the data were sorted according to their value and percentage after all radiographs in that age range had been evaluated. The number in the middle was then chosen as the median value. For example, in the age group of 5 years and the Demirjian stages of the first central incisor (Tooth No. 11) were C (9), D (64), E (18) and F (7), then, the median value became the D stage. These medians were used to construct tables for both genders and ethnic groups.

A number of descriptive and statistical analyses were performed to examine the stages of tooth development in an in depth manner, encompassing the 4 quadrants of dental arches in three ethnic groups. In accordance with the objectives, these statistical analyses were performed to:

a. determine the pattern of tooth development within dental arches and between age groups, gender and ethnic groups,

b. compare the level of tooth development within dental arches between gender and ethnic groups, and

c. develop population specific standards for age estimation in Malaysians, partitioned by ethnicity and gender.

The results of the descriptive and statistical analyses were thus presented as follows:

i. Demographics of 4614 subjects based on age, gender and ethnicity.
ii. Distribution of the complete dental developmental stages for grades A-H and O in subjects within the age group and across age group respectively.
iii. Distribution of the complete dental developmental stages for grades A-H and O in subjects from ages 5-18 years in the maxilla and mandible.
iv. Distribution of the complete dental developmental stages for grades A-H and O in subjects aged 5-18 years in males and females.
v. Frequency distribution of the complete dental developmental stages for grades A-H and O in subjects from ages 5-18 years.
vi. Frequency distribution of the complete dental developmental stages for grades A-H and O in subjects from ages 5-18 years in the maxilla and mandible.
vii. Frequency distribution of the complete dental developmental stages for grades A-H and O in subjects from ages 5-18 years in males and females.
viii. Frequency and percentage distribution of the complete dental developmental stages for grades A-H and O in Malay subjects aged 5-18 years.
ix. Frequency and percentage distribution of the complete dental developmental stages for grades A-H and O in Chinese subjects aged 5-18 years.
x. Frequency and percentage distribution of the complete dental developmental stages for grades A-H and O in Indian subjects aged 5-18 years.

It should be noted that samples with Stage X were excluded from data analysis, which were indicated for teeth that cannot be graded and do not have self-weighted scores.

3.7 Data analysis

3.7.1 Chronological age calculation

The gold standard of CA was calculated in days, by subtracting date of birth from the date the radiograph was taken and dividing by 365.25 to convert to decimal years. To the total of 365 days, 0.25 day was added to take into account of the leap year that occurs once in four years.

3.7.2 Dental age estimation

DA estimation was based on the development of the eight and seven left permanent mandibular teeth respectively. Tooth formation was divided into eight stages and scores were obtained. The values were then summed up and the total maturity score indicated the DA based on standardised tables of the original Demirjian (1973) and modified Chaillet & Demirjian (2004) methods, respectively.

3.7.3 Evaluation of reproducibility

Ninety DPTs were scored for a second time after a period of 2 weeks to assess inter-examiner reproducibility and after another 2 weeks for intra-examiner reproducibility. Cohen's kappa calculations were performed by comparing the TDS scores between the original (student) and re-assessed (supervisor) DPTs.

3.7.4 Calculation of accuracy

Accuracy of dental age estimation was defined by how closely chronological age could be predicted and was measured as the difference between chronological age and dental age. The chronological age was subtracted from the dental age; a positive result indicated over-estimation, zero meant that dental age and chronological ages were identical and a negative result indicated under-estimation.

3.7.5 Statistical analysis of dental age estimation

The mean and standard deviation of chronological ages were obtained from the sample **(**Erdem et al., 2013). Analysis of correlation was carried out between chronological age, dental age and Demirjian's scores. The difference between the dental age and the chronological age was determined with the paired t-test for each gender.

A prediction model for Demirjian's score was established by using ANN analysis, specifically the multilayer perceptron function (Corsini et al., 2005). This prediction model was applied to obtain a new Demirjian's score, which was converted to the new dental age (NDA). The tables of dental maturity scores were established for both genders separately. A new method for evaluating the dental age in a population of Malaysian children was established. The difference between the new dental and chronological ages were evaluated statistically at the $p < 0.05$ level.

A summary of the work flow is shown in **Fig. 3.3**, with the sub-populations for each part of the study depicted in a Venn chart for clarity (**Fig. 3.4**).

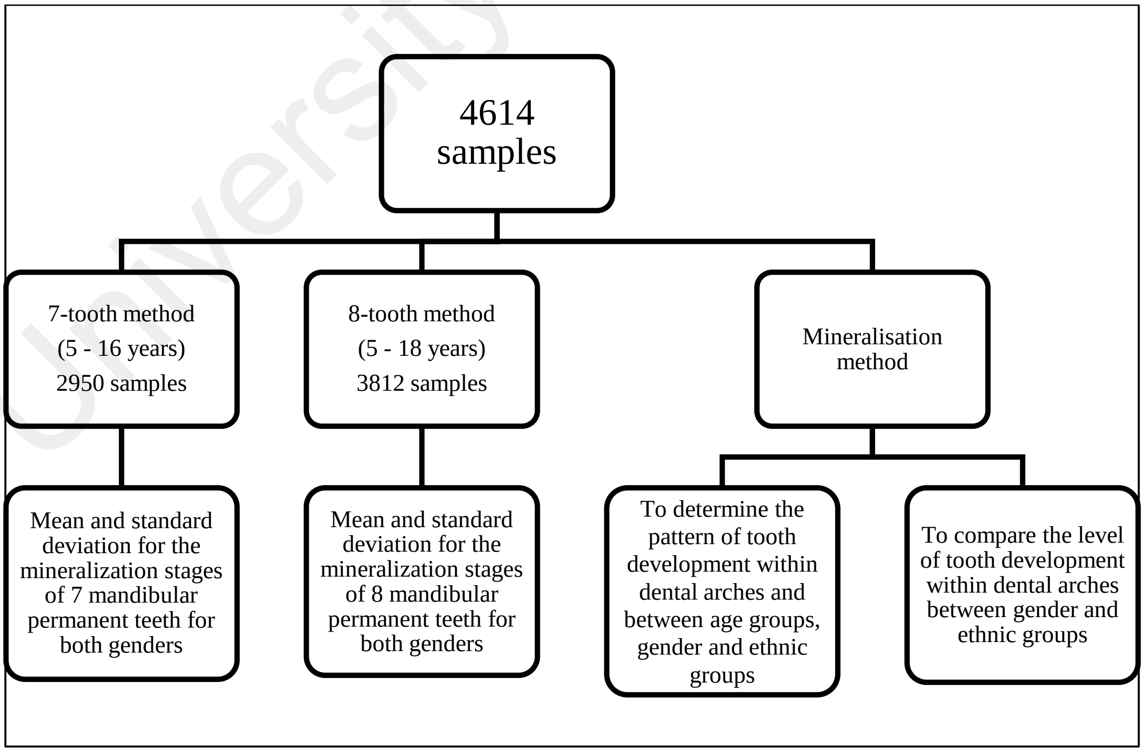

Figure 3.3 Simplified flow chart of study approach and data analysis

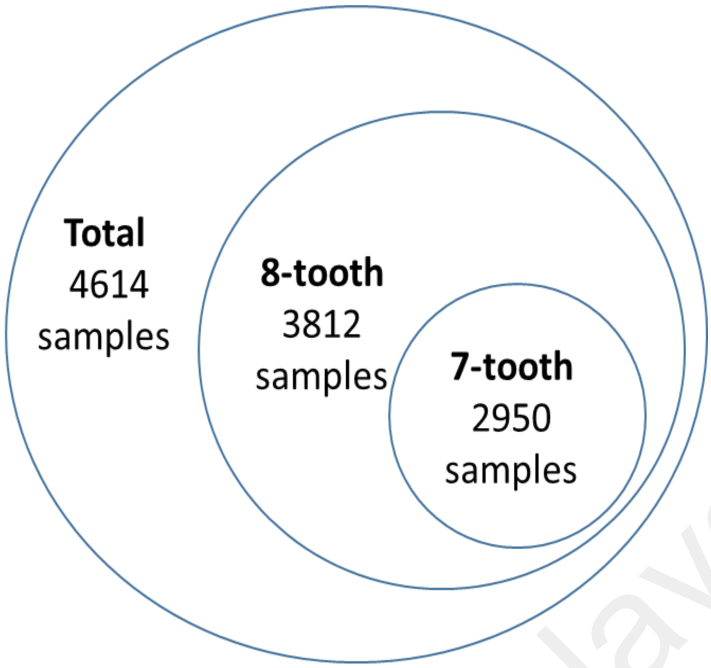

Figure 3.4 Venn chart depicting number of samples used in the respective 7-tooth, 8-tooth, and mineralisation methods

In addition, a more detailed flow chart of the whole study is shown in **Fig. 3.5**. The results were to be presented in three main parts based on the work flow: forensic original method, forensic modified method and mineralisation method.

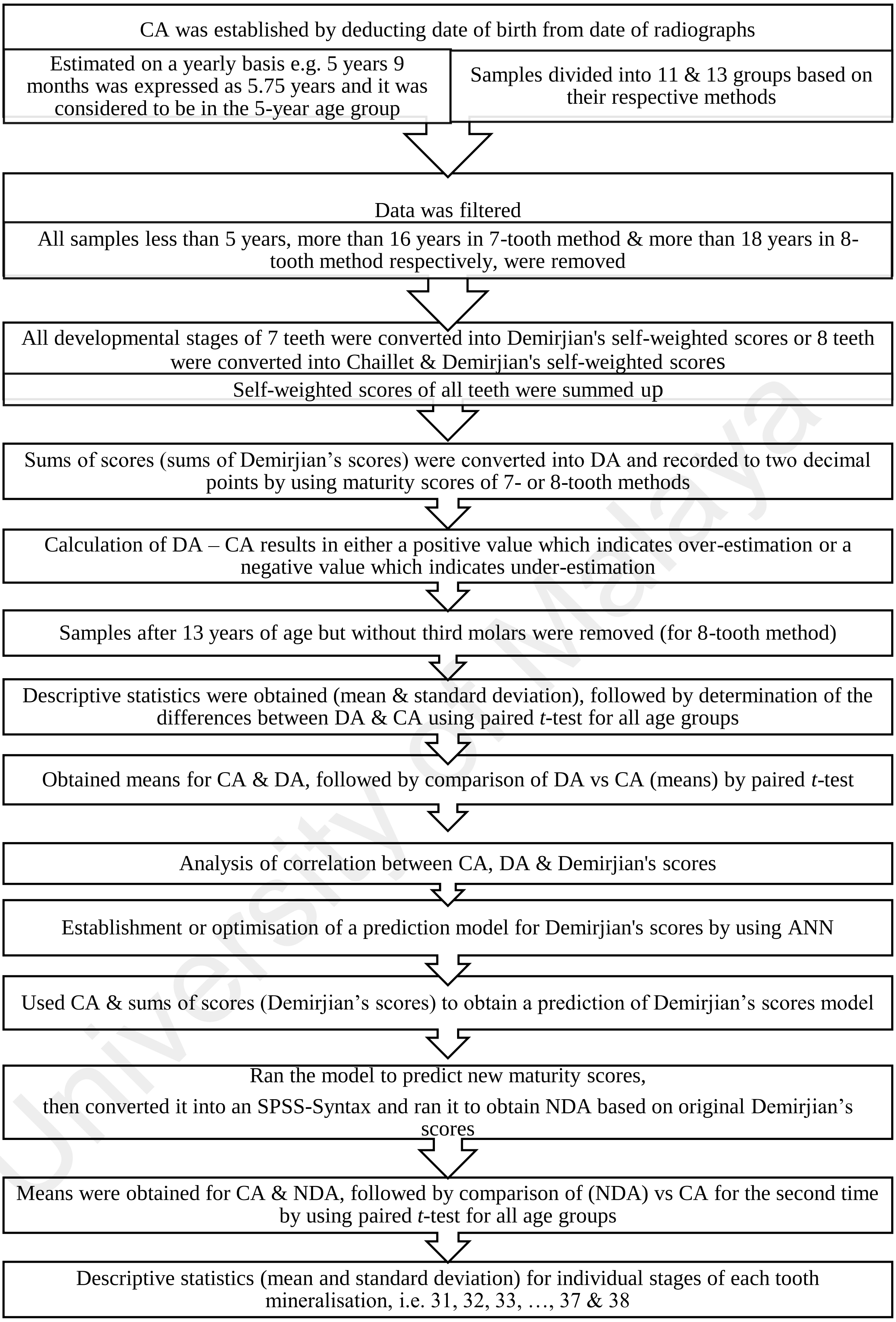

Figure 3.5 Flow chart of study. CA: chronological age; DA: dental age; NDA: new dental age; ANN: artificial neural networks.

CHAPTER 4: RESULTS

4.1 Inter-examiner and intra-examiner reliability

The calculated Cohen kappa values ranged between 0.61 and 1.00 for the intra-examiner test, which indicated that the examiner was consistent when the radiographs were subsequently reviewed (**Table 4.1a**), as there was substantial agreement between the review sessions.

Table 4.1a Intra-examiner reliability

Tooth No.	Kappa	Interpretation	Tooth No.	Kappa	Interpretation
18	0.825	Almost perfect agreement	38	0.854	Almost perfect agreement
17	0.729	Moderate agreement	37	0.661	Substantial agreement
16	0.762	Substantial agreement	36	0.904	Almost perfect agreement
15	0.928	Almost perfect agreement	35	0.807	Substantial agreement
14	0.858	Almost perfect agreement	34	0.927	Almost perfect agreement
13	0.799	Substantial agreement	33	0.800	Substantial agreement
12	0.764	Substantial agreement	32	0.829	Almost perfect agreement
11	0.838	Almost perfect agreement	31	0.815	Almost perfect agreement
21	0.865	Almost perfect agreement	41	0.870	Almost perfect agreement
22	0.844	Almost perfect agreement	42	0.745	Substantial agreement
23	0.728	Substantial agreement	43	0.747	Substantial agreement
24	0.850	Almost perfect agreement	44	0.805	Substantial agreement
25	0.879	Almost perfect agreement	45	0.761	Substantial agreement
26	0.787	Substantial agreement	46	0.938	Almost perfect agreement
27	0.707	Substantial agreement	47	0.758	Substantial agreement
28	0.770	Substantial agreement	48	0.831	Almost perfect agreement

Data was analysed based on 10% of total samples (50). Kappa values were expressed as symmetric measures. Interpretation was performed based on the method of Landis & Koch (1977), as follows:

Kappa values	**Interpretation**
< 0	Poor agreement
0.0 – 0.20	Slight agreement
0.21 – 0.40	Fair agreement
0.41 – 0.60	Moderate agreement
0.61 – 0.80	Substantial agreement
0.81 – 1.00	Almost perfect agreement

In addition, the calculated Cohen kappa values ranged between 0.81 – 1.00 for the inter-examiner reliability test, which indicated substantial to almost perfect agreement between the two examiners (**Table 4.1b**).

Table 4.1b Inter-examiner reliability

Tooth No.	Kappa	Interpretation	Tooth No.	Kappa	Interpretation
18	0.894	Almost perfect agreement	38	0.839	Almost perfect agreement
17	0.741	Substantial agreement	37	0.749	Substantial agreement
16	0.781	Substantial agreement	36	0.885	Almost perfect agreement
15	0.874	Almost perfect agreement	35	0.847	Almost perfect agreement
14	0.871	Almost perfect agreement	34	0.858	Almost perfect agreement
13	0.841	Almost perfect agreement	33	0.793	Substantial agreement
12	0.715	Substantial agreement	32	0.870	Almost perfect agreement
11	0.834	Almost perfect agreement	31	0.793	Substantial agreement
21	0.849	Almost perfect agreement	41	0.852	Almost perfect agreement
22	0.845	Almost perfect agreement	42	0.791	Substantial agreement
23	0.812	Almost perfect agreement	43	0.779	Substantial agreement
24	0.828	Almost perfect agreement	44	0.844	Almost perfect agreement
25	0.853	Almost perfect agreement	45	0.821	Almost perfect agreement
26	0.811	Almost perfect agreement	46	0.923	Almost perfect agreement
27	0.738	Substantial agreement	47	0.816	Almost perfect agreement
28	0.859	Almost perfect agreement	48	0.855	Almost perfect agreement

Data was analysed based on 100 samples. Kappa values were expressed as symmetric measures. Interpretation was performed based on the method of Landis & Koch (1977), as follows:

Kappa values	Interpretation
< 0	Poor agreement
0.0 – 0.20	Slight agreement
0.21 – 0.40	Fair agreement
0.41 – 0.60	Moderate agreement
0.61 – 0.80	Substantial agreement
0.81 – 1.00	Almost perfect agreement

4.2 Forensic methods

This section presents results based on the original and modified Demirjian's methods.

4.2.1 Dental age estimation using original Demirjian's method 1973

In this section, the samples that were analysed were based on those children aged 5-16 years old. Overall, Malays represented the largest group followed by Chinese and then Indians, with males and females for each ethnic group being represented in approximately equal proportions of 50% of each (**Table 4.2a**).

Table 4.2a: Demographics of study subjects (5 – 16 years)

Ethnicity	Sex	N (%)	Total by ethnicity (%)
Malay	Male	648 (52.4)	1236 (41.9)
	Female	588 (47.5)	
Chinese	Male	483 (51.8)	932 (31.6)
	Female	449 (48.2)	
Indian	Male	400 (51.2)	782 (26.5)
	Female	382 (48.8)	
Total		2950 (100.0)	

Upon examination of the data by age groups for each ethnicity, it was observed that the Malay subjects were represented by 50 subjects and above for most of the age groups, except for the 6-, 7- and 15-year-olds (**Table 4.2b**). Similarly, for the Chinese and Indian subjects, the number of subjects in the 5-8-year-old groups was less than 50.

Table 4.2b: Sample distribution of study subjects by age group (5 – 16 years)

Ethnic	Chronological age (years)	Male (%)	Female (%)	Total (%)
Malay	**5.0-5.9**	70 (10.80)	60 (10.20)	130 (10.52)
	6.0-6.9	45 (6.94)	36 (6.12)	81 (6.55)
	7.0-7.9	66 (10.19)	48 (8.16)	114 (9.22)
	8.0-8.9	78 (12.04)	51 (8.67)	129 (10.44)
	9.0-9.9	58 (8.95)	63 (10.71)	121 (9.79)
	10.0-10.9	57 (8.80)	64 (10.88)	121 (9.79)
	11.0-11.9	65 (10.03)	57 (9.69)	122 (9.87)
	12.0-12.9	59 (9.10)	53 (9.01)	112 (9.06)
	13.0-13.9	53 (8.18)	62 (10.54)	115 (9.30)
	14.0-14.9	47 (7.25)	56 (9.52)	103 (8.33)
	15.0-15.9	50 (7.72)	38 (6.46)	88 (7.12)
	Total	648 (100.00)	588 (100.00)	1236 (100.00)
Chinese	**5.0-5.9**	32 (6.63)	17 (3.79)	49 (5.26)
	6.0-6.9	31 (6.42)	18 (4.01)	49 (5.26)
	7.0-7.9	45 (9.32)	16 (3.56)	61 (6.55)
	8.0-8.9	49 (10.14)	44 (9.80)	93 (9.98)
	9.0-9.9	31 (6.42)	48 (10.69)	79 (8.48)
	10.0-10.9	63 (13.04)	43 (9.58)	106 (11.37)
	11.0-11.9	34 (7.04)	55 (12.25)	89 (9.55)
	12.0-12.9	63 (13.04)	41 (9.13)	104 (11.16)
	13.0-13.9	34 (7.04)	50 (11.14)	84 (9.01)
	14.0-14.9	46 (9.52)	47 (10.47)	93 (9.98)
	15.0-15.9	55 (11.39)	70 (15.59)	125 (13.41)
	Total	483 (100)	449 (100)	932 (100)
Indian	**5.0-5.9**	13 (3.25)	9 (2.36)	22 (2.81)
	6.0-6.9	19 (4.75)	15 (3.93)	34 (4.35)
	7.0-7.9	23 (5.75)	11 (2.88)	34 (4.35)
	8.0-8.9	29 (7.25)	36 (9.42)	65 (8.31)
	9.0-9.9	33 (8.25)	33 (8.64)	66 (8.44)
	10.0-10.9	41 (10.25)	43 (11.26)	84 (10.74)
	11.0-11.9	50 (12.5)	45 (11.78)	95 (12.15)
	12.0-12.9	49 (12.25)	46 (12.04)	95 (12.15)
	13.0-13.9	45 (11.25)	54 (14.14)	99 (12.66)
	14.0-14.9	49 (12.25)	48 (12.57)	97 (12.40)
	15.0-15.9	49 (12.25)	42 (10.99)	91 (11.64)
	Total	400 (100.00)	382 (100.00)	782 (100.00)

4.2.1.1 Dental age estimation in Malays using original Demirjian's method 1973

A total of 1236 Malay samples were analysed (**Table 4.3**).

Table 4.3: Distribution of Malay subjects by age and sex

Chronological age (years)	Male (%)	Female (%)	Total (%)
5.0-5.9	70 (10.80)	60 (10.20)	130 (10.52)
6.0-6.9	45 (6.94)	36 (6.12)	81 (6.55)
7.0-7.9	66 (10.19)	48 (8.16)	114 (9.22)
8.0-8.9	78 (12.04)	51 (8.67)	129 (10.44)
9.0-9.9	58 (8.95)	63 (10.71)	121 (9.79)
10.0-10.9	57 (8.80)	64 (10.88)	121 (9.79)
11.0-11.9	65 (10.03)	57 (9.69)	122 (9.87)
12.0-12.9	59 (9.10)	53 (9.01)	112 (9.06)
13.0-13.9	53 (8.18)	62 (10.54)	115 (9.30)
14.0-14.9	47 (7.25)	56 (9.52)	103 (8.33)
15.0-15.9	50 (7.72)	38 (6.46)	88 (7.12)
Total	648 (100.00)	588 (100.00)	1236 (100.00)

Comparison between CA and DA in Malay males showed significant differences in the 5- to 7-year-olds and 11- to 14-year-olds (**Table 4.4a**).

Table 4.4a: Comparison of chronological age and dental age as determined by using original Demirjian's standards in Malay males

Age	N	CA		DA		DA-CA		95 % CI		*t*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	70	5.43	0.26	5.81	0.78	0.39	0.62	0.24	0.53	5.17	0.00*
6.0-6.9	45	6.47	0.27	7.23	0.36	0.77	0.28	0.68	0.85	18.32	0.00*
7.0-7.9	66	7.48	0.26	7.83	0.22	0.34	0.24	0.28	0.40	11.42	0.00*
8.0-8.9	78	8.47	0.29	8.51	0.56	0.04	0.49	-0.07	0.15	0.74	0.46
9.0-9.9	58	9.51	0.31	9.52	0.73	0.01	0.63	-0.16	0.17	0.09	0.93
10.0-10.9	57	10.41	0.28	10.52	1.09	0.11	1.00	-0.15	0.38	0.84	0.41
11.0-11.9	65	11.46	0.28	11.91	1.31	0.44	1.28	0.12	0.76	2.78	0.01*
12.0-12.9	59	12.46	0.31	12.88	1.38	0.42	1.30	0.08	0.76	2.49	0.02*
13.0-13.9	53	13.50	0.27	14.39	1.43	0.89	1.39	0.51	1.27	4.65	0.00*
14.0-14.9	47	14.57	0.28	15.25	0.93	0.68	0.99	0.39	0.97	4.72	0.00*
15.0-15.9	50	15.48	0.28	15.56	0.87	0.08	0.81	-0.15	0.31	0.72	0.47

CA: Chronological age. DA: Dental age. Paired samples t-test. *Statistically significant at the 0.05 level.

Similarly, comparison between CA and DA in Malay females showed significant differences in the 5- to 7-year-olds and 11- to 14-year-olds (**Table 4.4b**).

Table 4.4b: Comparison of chronological age and dental age as determined by using original Demirjian's standards in Malay females

Age	N	CA		DA		DA-CA		95 % CI		*t*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	60	5.42	0.29	5.84	0.73	0.41	0.54	0.27	0.55	5.92	0.00*
6.0-6.9	36	6.48	0.32	7.17	0.30	0.70	0.27	0.61	0.79	15.69	0.00*
7.0-7.9	48	7.52	0.30	7.71	0.23	0.19	0.24	0.12	0.26	5.44	0.00*
8.0-8.9	51	8.46	0.29	8.41	0.46	-0.06	0.49	-0.20	0.08	-0.85	0.40
9.0-9.9	63	9.51	0.27	9.59	0.92	0.07	0.87	-0.15	0.29	0.66	0.51
10.0-10.9	64	10.43	0.29	10.57	0.99	0.14	0.97	-0.10	0.38	1.14	0.26
11.0-11.9	57	11.51	0.29	11.98	0.95	0.47	0.91	0.23	0.71	3.87	0.00*
12.0-12.9	53	12.47	0.28	12.88	1.12	0.41	1.08	0.11	0.71	2.78	0.01*
13.0-13.9	62	13.44	0.30	13.80	1.16	0.36	1.15	0.07	0.65	2.45	0.02*
14.0-14.9	56	14.48	0.30	14.72	0.86	0.24	0.81	0.02	0.45	2.19	0.03*
15.0-15.9	38	15.42	0.32	15.27	0.70	-0.15	0.53	-0.32	0.03	-1.73	0.09

CA: Chronological age. DA: Dental age. Paired samples t-test, * Statistically significant at the 0.05 level.

Overall, the difference between CA and DA in Malays was significant when values were pooled together (**Table 4.5**). The difference represented over-estimation by 0.36 years, equivalent to 4.3 months in males, whereas in females it was 0.25 years, which was equivalent to 3.0 months.

Table 4.5: Summary for comparison of chronological age and dental age (determined by using original Demirjian's method) in Malays

Gender	N	CA	DA	DA-CA	t	p
Male	648	10.22 ± 3.12	10.58 ± 3.3	0.36 ± 0.93	9.729	0.0001*
Female	588	10.48 ± 3.06	10.74 ± 3.12	0.25 ± 0.83	7.348	0.0001*

Values are mean ± SD. CA: Chronological age. DA: Dental age. Paired samples t-test, *Significant at the 0.05 level.

The correlation between CA and Demirjian's scores was very high (**Table 4.6**). However, although the correlation was high, the difference between CA and scores was significant.

Table 4.6: Correlation between chronological age, Demirjian's scores and predicted values for Demirjian's scores in Malays

		Chronological age	
		Male	**Female**
Demirjian's score	r	0.982*	0.986*
	p	0.0001	0.0001
Predicted value for Demirjian's score	R/r	0.982*	0.986*
	P	0.0001	0.0001

Correlation analysis, r; *Significant at the 0.01 level (2-tailed).

The relationship between the scores obtained from CA and Demirjian's scores in Malay males when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.2a** and **4.2b**, respectively.

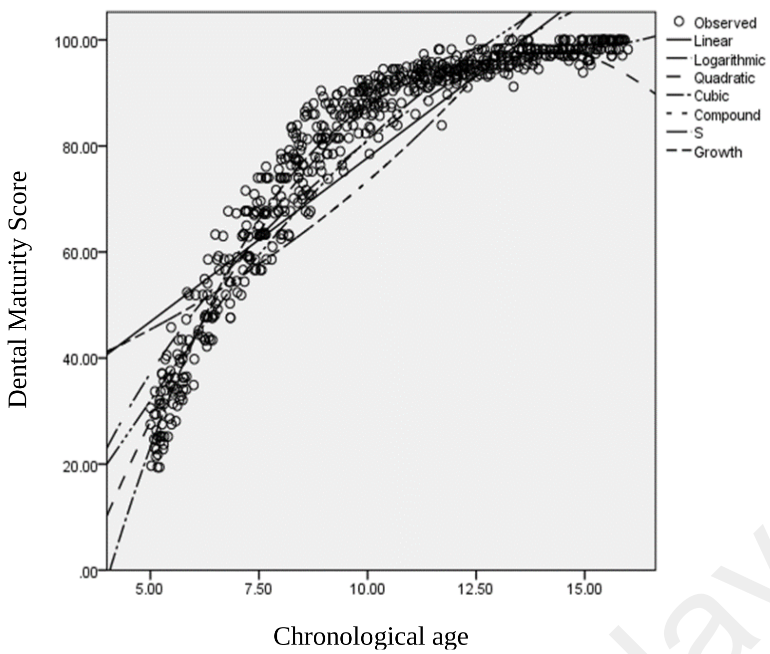

Figure 4.2a: Distribution of score sums based on Demirjian's scores plotted against median values of obtained scores for Malay males by using regression analysis

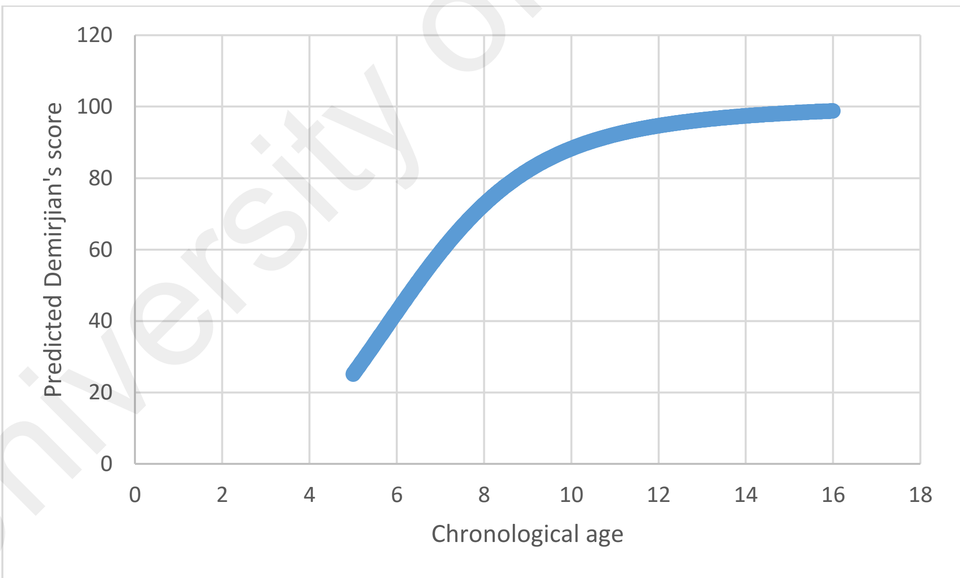

Figure 4.2b: Distribution of score sums based on Demirjian's scores plotted against median values of obtained scores for Malay males following treatment of data with ANN

The relationship between the scores obtained and Demirjian's scores in Malay females when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.2c** and **4.2d**, respectively.

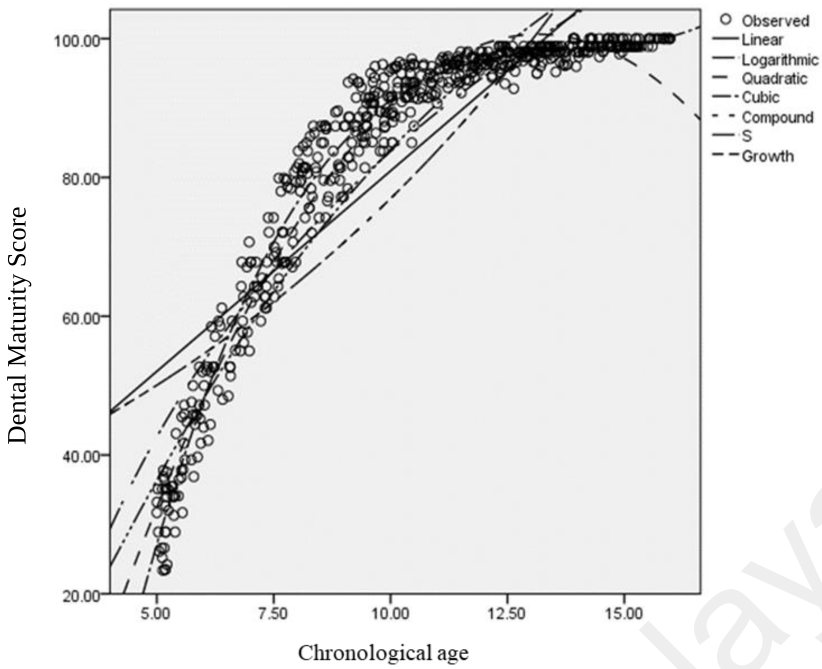

Figure 4.2c: Distribution of median values of obtained scores plotted against score sums based on Demirjian's scores for Malay females by using regression analysis

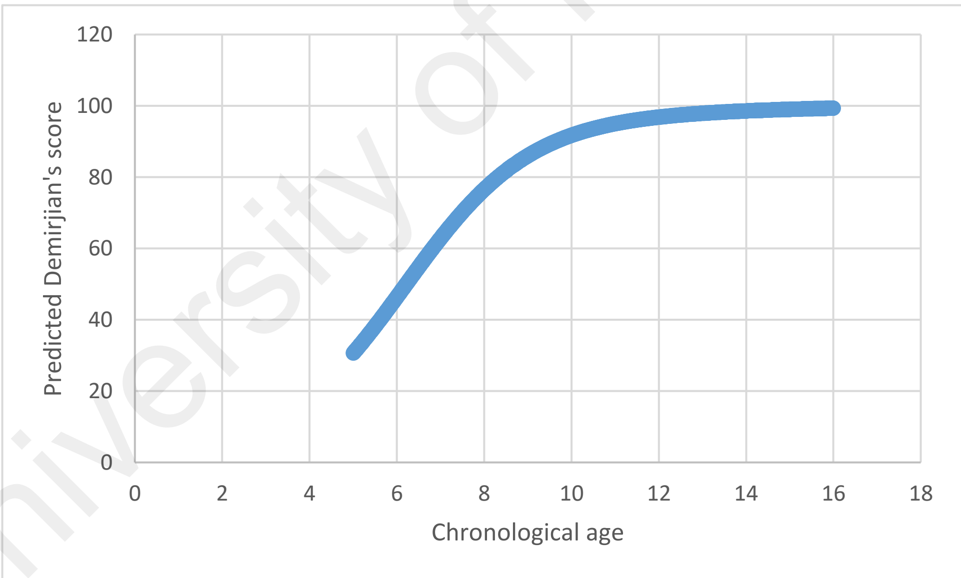

Figure 4.2d: Distribution of median values of obtained scores plotted against score sums based on Demirjian's scores for Malay females following treatment of data with ANN

With both the Malay male and female samples, there is 1 hidden layer consisting of 3 subunits in male and 2 subunits in female that connect the input (CA) to the output (score), after ANN processing (**Figures 4.3a** and **b**, respectively).

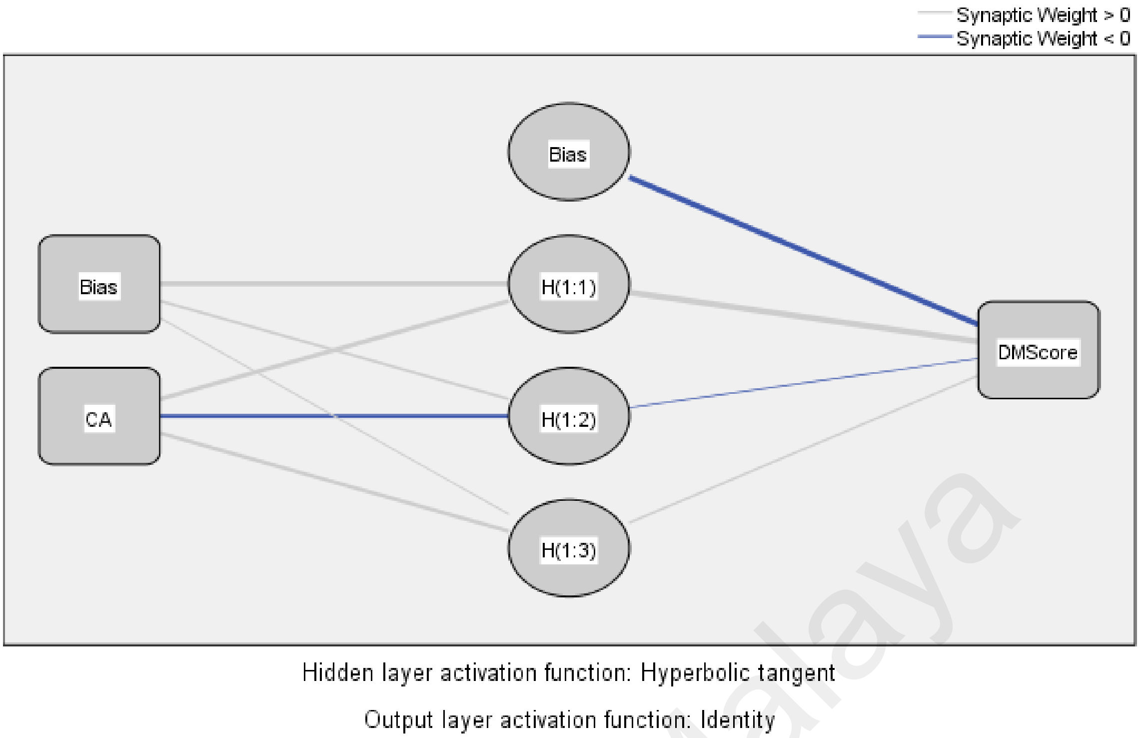

Figure 4.3a: Relationship between chronological age (CA) and Demirjian's score (DMScore) in Malay males based on the 7-tooth method. H: hidden layer.

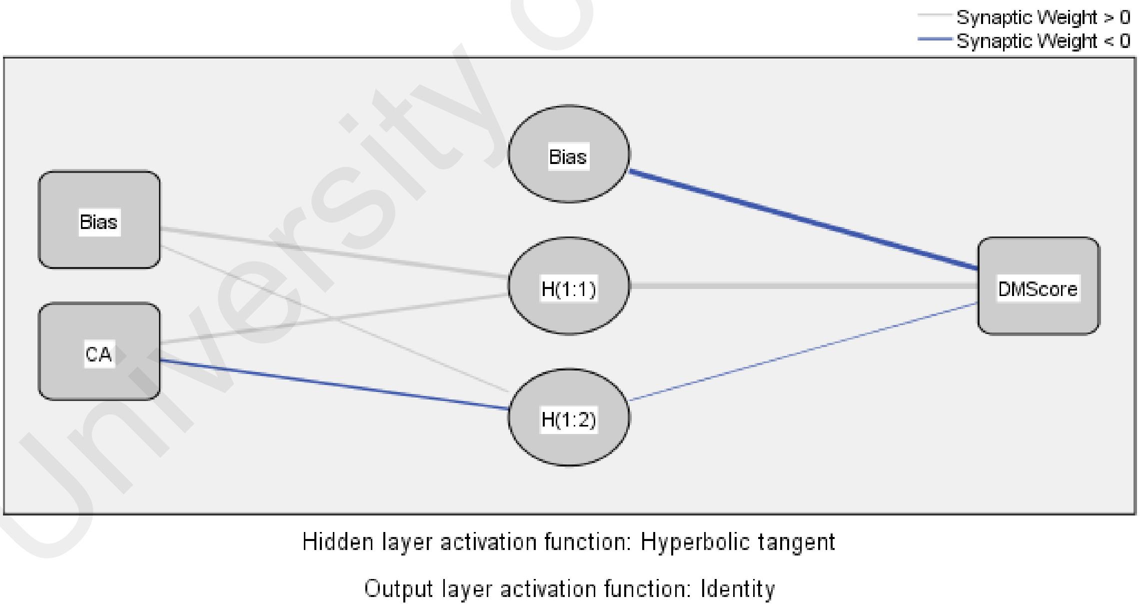

Figure 4.3b: Relationship between chronological age (CA) and Demirjian's score (DMScore) in Malay females based on the 7-tooth method. H: hidden layer.

Following treatment of data with ANN, the overall difference between CA and NDA in Malays, when values were pooled together and compared using paired-samples t-test, was no longer significant (**Table 4.7**). The difference was 0.05 years, equivalent to 0.6 months or 18 days in males, whereas it was 0.04 years, which was equivalent to 0.48 months or about 14 days in females.

Table 4.7: Summary for comparison of chronological age and new dental age (determined by using ANN) in Malays

Gender	N	CA	NDA	NDA-CA	*t*	p
Male	648	10.22 ± 3.12	10.27 ± 3.23	0.05 ± 0.83	1.465	0.143
Female	588	10.48 ± 3.06	10.52 ± 3.15	0.04 ± 0.79	1.160	0.247

CA: Chronological age. NDA: New dental age. Values are mean ± SD. Paired samples t-test, $p>0.05$.

When the overall data after being subjected to ANN analysis was sliced by age, the difference for each category of age was also not significant for males and females (**Tables 4.8a** and **b**, respectively).

Table 4.8a: Comparison of chronological age and new dental age as determined by using ANN in Malay males

Age	N	CA		NDA		NDA-CA		95 % CI		*t*	p
		Mean	SD	Mean	SD	Mean	SD	lower	upper		
5.0-5.9	70	5.43	0.26	5.46	0.39	0.04	0.28	-0.03	0.10	1.06	0.29
6.0-6.9	45	6.47	0.27	6.51	0.44	0.04	0.35	-0.06	0.15	0.86	0.40
7.0-7.9	66	7.48	0.26	7.41	0.43	-0.07	0.38	-0.16	0.02	-1.51	0.14
8.0-8.9	78	8.47	0.29	8.48	0.72	0.02	0.63	-0.12	0.16	0.26	0.79
9.0-9.9	58	9.51	0.31	9.63	0.71	0.12	0.61	-0.04	0.28	1.52	0.14
10.0-10.9	57	10.41	0.28	10.55	0.85	0.14	0.77	-0.07	0.34	1.33	0.19
11.0-11.9	65	11.46	0.28	11.66	1.07	0.19	1.04	-0.06	0.45	1.50	0.14
12.0-12.9	59	12.46	0.31	12.39	1.14	-0.06	1.08	-0.34	0.22	-0.44	0.66
13.0-13.9	53	13.50	0.27	13.74	1.37	0.24	1.35	-0.13	0.61	1.31	0.20
14.0-14.9	47	14.57	0.28	14.65	1.07	0.09	1.09	-0.23	0.41	0.55	0.58
15.0-15.9	50	15.48	0.28	15.26	1.08	-0.22	1.01	-0.51	0.07	-1.53	0.13

CA: Chronological age. NDA: New dental age. Paired samples t-test, p>0.05.

Table 4.8b: Comparison of chronological age and new dental age as determined by using ANN in Malay females

Age	N	CA		NDA		NDA-CA		95 % CI		*t*	p
		Mean	SD	Mean	SD	Mean	SD	lower	upper		
5.0-5.9	60	5.42	0.29	5.45	0.39	0.03	0.23	-0.03	0.09	0.91	0.37
6.0-6.9	36	6.48	0.32	6.53	0.41	0.05	0.31	-0.05	0.15	0.98	0.34
7.0-7.9	48	7.52	0.30	7.49	0.47	-0.03	0.37	-0.14	0.07	-0.63	0.53
8.0-8.9	51	8.46	0.29	8.54	0.48	0.07	0.51	-0.07	0.22	1.00	0.32
9.0-9.9	63	9.51	0.27	9.61	0.76	0.10	0.72	-0.08	0.28	1.08	0.28
10.0-10.9	64	10.43	0.29	10.42	0.81	-0.01	0.80	-0.21	0.19	-0.11	0.92
11.0-11.9	57	11.51	0.29	11.58	0.80	0.07	0.76	-0.14	0.27	0.65	0.52
12.0-12.9	53	12.47	0.28	12.48	1.15	0.00	1.12	-0.30	0.31	0.03	0.98
13.0-13.9	62	13.44	0.30	13.53	1.34	0.09	1.33	-0.25	0.43	0.55	0.59
14.0-14.9	56	14.48	0.30	14.60	1.05	0.12	0.99	-0.15	0.38	0.90	0.37
15.0-15.9	38	15.42	0.32	15.29	0.69	-0.13	0.53	-0.31	0.04	-1.54	0.13

CA: Chronological age. NDA: New dental age. Paired samples t-test, p>0.05.

Thus, based on the data that was subjected to ANN analysis, dental scores that accurately predicted the CA were generated (**Tables 4.9** and **4.10**), for males and females respectively.

Table 4.9: Scores calculated with ANN and dental age scales for Malay males

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	25.07	9	82.06	13	96.28
5.1	26.76	9.1	82.81	13.1	96.41
5.2	28.47	9.2	83.53	13.2	96.54
5.3	30.19	9.3	84.22	13.3	96.66
5.4	31.93	9.4	84.87	13.4	96.78
5.5	33.68	9.5	85.5	13.5	96.89
5.6	35.45	9.6	86.1	13.6	97
5.7	37.21	9.7	86.67	13.7	97.11
5.8	38.98	9.8	87.22	13.8	97.21
5.9	40.75	9.9	87.74	13.9	97.31
6	42.51	10	88.24	14	97.4
6.1	44.26	10.1	88.72	14.1	97.49
6.2	46	10.2	89.17	14.2	97.58
6.3	47.73	10.3	89.61	14.3	97.67
6.4	49.44	10.4	90.02	14.4	97.75
6.5	51.13	10.5	90.42	14.5	97.83
6.6	52.8	10.6	90.8	14.6	97.91
6.7	54.43	10.7	91.16	14.7	97.98
6.8	56.05	10.8	91.5	14.8	98.06
6.9	57.63	10.9	91.83	14.9	98.13
7	59.18	11	92.15	15	98.2
7.1	60.69	11.1	92.45	15.1	98.26
7.2	62.17	11.2	92.74	15.2	98.33
7.3	63.61	11.3	93.02	15.3	98.39
7.4	65.01	11.4	93.28	15.4	98.45
7.5	66.38	11.5	93.53	15.5	98.51
7.6	67.7	11.6	93.77	15.6	98.57
7.7	68.99	11.7	94.01	15.7	98.62
7.8	70.23	11.8	94.23	15.8	98.68
7.9	71.43	11.9	94.44	15.9	98.73
8	72.59	12	94.64	16	98.78
8.1	73.71	12.1	94.84		
8.2	74.79	12.2	95.03		
8.3	75.84	12.3	95.21		
8.4	76.84	12.4	95.38		
8.5	77.8	12.5	95.54		
8.6	78.72	12.6	95.7		
8.7	79.61	12.7	95.86		
8.8	80.46	12.8	96		
8.9	81.28	12.9	96.14		

Table 4.10: Scores calculated with ANN and dental age scales for Malay females

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	30.65	9	86.03	13	97.94
5.1	32.09	9.1	86.75	13.1	98.02
5.2	33.57	9.2	87.44	13.2	98.1
5.3	35.09	9.3	88.09	13.3	98.17
5.4	36.63	9.4	88.7	13.4	98.24
5.5	38.21	9.5	89.29	13.5	98.31
5.6	39.81	9.6	89.84	13.6	98.37
5.7	41.43	9.7	90.36	13.7	98.43
5.8	43.08	9.8	90.86	13.8	98.49
5.9	44.74	9.9	91.33	13.9	98.55
6	46.41	10	91.77	14	98.6
6.1	48.08	10.1	92.19	14.1	98.66
6.2	49.77	10.2	92.58	14.2	98.71
6.3	51.45	10.3	92.95	14.3	98.76
6.4	53.12	10.4	93.3	14.4	98.8
6.5	54.79	10.5	93.63	14.5	98.85
6.6	56.45	10.6	93.95	14.6	98.89
6.7	58.09	10.7	94.24	14.7	98.93
6.8	59.71	10.8	94.52	14.8	98.98
6.9	61.3	10.9	94.78	14.9	99.02
7	62.87	11	95.03	15	99.05
7.1	64.41	11.1	95.27	15.1	99.09
7.2	65.92	11.2	95.49	15.2	99.13
7.3	67.39	11.3	95.7	15.3	99.16
7.4	68.83	11.4	95.89	15.4	99.2
7.5	70.23	11.5	96.08	15.5	99.23
7.6	71.58	11.6	96.26	15.6	99.26
7.7	72.9	11.7	96.42	15.7	99.29
7.8	74.17	11.8	96.58	15.8	99.33
7.9	75.4	11.9	96.73	15.9	99.36
8	76.58	12	96.87	16	99.38
8.1	77.72	12.1	97		
8.2	78.82	12.2	97.13		
8.3	79.87	12.3	97.25		
8.4	80.87	12.4	97.36		
8.5	81.84	12.5	97.47		
8.6	82.76	12.6	97.57		
8.7	83.64	12.7	97.67		
8.8	84.47	12.8	97.77		
8.9	85.27	12.9	97.85		

4.2.1.2 Dental age estimation in the Chinese using original Demirjian's method 1973

A total of 932 radiographs collected from Chinese subjects were analysed (**Table 4.11**).

Table 4.11: Distribution of Chinese subjects based on age and sex

Chronological age (years)	Male (%)	Female (%)	Total (%)
5.0-5.9	32 (6.63)	17 (3.79)	49 (5.26)
6.0-6.9	31 (6.42)	18 (4.01)	49 (5.26)
7.0-7.9	45 (9.32)	16 (3.56)	61 (6.55)
8.0-8.9	49 (10.14)	44 (9.80)	93 (9.98)
9.0-9.9	31 (6.42)	48 (10.69)	79 (8.48)
10.0-10.9	63 (13.04)	43 (9.58)	106 (11.37)
11.0-11.9	34 (7.04)	55 (12.25)	89 (9.55)
12.0-12.9	63 (13.04)	41 (9.13)	104 (11.16)
13.0-13.9	34 (7.04)	50 (11.14)	84 (9.01)
14.0-14.9	46 (9.52)	47 (10.47)	93 (9.98)
15.0-15.9	55 (11.39)	70 (15.59)	125 (13.41)
Total	483 (100)	449 (100)	932 (100)

Comparison between CA and DA in Chinese males showed significant differences in the 5 to 8-year-olds and 11 to 15-year-olds (**Table 4.12a**).

Table 4.12a: Comparison of chronological age and dental age as determined by using original Demirjian's standards in Chinese males

Age	N	CA		DA		DA-CA		95 % CI		*t*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	32	5.47	0.32	6.18	0.71	0.72	0.47	0.55	0.89	8.64	0.00*
6.0-6.9	31	6.48	0.27	7.38	0.26	0.90	0.26	0.81	1.00	19.26	0.00*
7.0-7.9	45	7.51	0.27	7.95	0.22	0.44	0.23	0.37	0.51	12.84	0.00*
8.0-8.9	49	8.54	0.28	8.67	0.48	0.13	0.43	0.01	0.25	2.14	0.04*
9.0-9.9	31	9.41	0.30	9.58	0.76	0.17	0.71	-0.09	0.44	1.36	0.18
10.0-10.9	63	10.52	0.30	10.73	0.84	0.21	0.83	0.00	0.42	1.97	0.05
11.0-11.9	34	11.47	0.28	11.94	0.82	0.47	0.76	0.20	0.73	3.56	0.00*
12.0-12.9	63	12.46	0.31	13.02	1.37	0.56	1.39	0.21	0.91	3.21	0.00*
13.0-13.9	34	13.45	0.31	14.30	1.39	0.84	1.31	0.39	1.30	3.76	0.00*
14.0-14.9	46	14.47	0.28	15.13	0.95	0.66	1.02	0.35	0.96	4.36	0.00*
15.0-15.9	55	15.47	0.29	15.84	0.32	0.37	0.37	0.27	0.47	7.49	0.00*

CA: Chronological age. DA: Dental age. Paired samples t-test. *Statistically significant at the 0.05 level.

On the other hand, comparison between CA and DA in Chinese females showed significant differences in all age groups except for the 14-year-olds (**Table 4.12b**).

Table 4.12b: Comparison of chronological age and dental age as determined by using original Demirjian's standards in Chinese females

Age	N	CA		DA		DA-CA		95 % CI		*t/z*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9[a]	17	5.43	0.31	6.00	0.72	0.57	0.49	0.32	0.82	-3.15	0.00*
6.0-6.9[a]	18	6.42	0.27	7.30	0.17	0.88	0.23	0.76	0.99	-3.73	0.00*
7.0-7.9[a]	16	7.30	0.24	7.73	0.20	0.43	0.16	0.34	0.51	-3.52	0.00*
8.0-8.9	44	8.50	0.29	8.66	0.47	0.15	0.38	0.04	0.27	2.65	0.01*
9.0-9.9	48	9.56	0.29	9.90	0.88	0.34	0.76	0.11	0.56	3.05	0.00*
10.0-10.9	43	10.52	0.29	11.18	1.15	0.66	1.11	0.32	1.00	3.88	0.00*
11.0-11.9	55	11.48	0.27	12.08	1.24	0.60	1.14	0.29	0.91	3.89	0.00*
12.0-12.9	41	12.51	0.31	13.04	1.39	0.54	1.41	0.09	0.98	2.43	0.02*
13.0-13.9	50	13.54	0.31	14.12	1.26	0.58	1.25	0.23	0.94	3.28	0.00*
14.0-14.9	47	14.48	0.29	14.52	1.02	0.04	1.00	-0.26	0.33	0.26	0.80
15.0-15.9	70	15.46	0.29	15.20	0.82	-0.26	0.82	-0.45	-0.06	-2.61	0.01*

CA: Chronological age. DA: Dental age. Paired samples t-test. *Statistically significant at the 0.05 level.
a: Based on Wilcoxon test due to small sample size.

Overall, the difference between CA and DA in Chinese subjects was significant when values were pooled together (**Table 4.13**). The difference in over-estimation was by 0.47 years, equivalent to 5.6 months in males, whereas in females it was 0.34 years, which was equivalent to 4.1 months.

Table 4.13: Summary for comparison of chronological age and dental age (determined by using original Demirjian's method) in Chinese subjects

Gender	N	CA	DA	DA-CA	*t*	p
Male	483	10.84 ± 3.08	11.31 ± 3.19	0.47 ± 0.86	11.970	0.0001*
Female	449	11.57 ± 2.91	11.90 ± 2.90	0.34 ± 1.01	7.054	0.0001*

Values are mean ± SD. CA: Chronological age. DA: Dental age. Paired samples t-test. *Significant at the 0.05 level.

This difference between CA and scores contrasted with the correlation between CA and Demirjian's scores which was highly significant ($p<0.001$; **Table 4.14**).

Table 4.14: Correlation between chronological age, Demirjian's scores and predicted values for Demirjian's scores in Chinese subjects

		Chronological age	
		Male	**Female**
Demirjian's score	r	0.984**	0.986**
	p	0.0001	0.0001
Predicted value for Demirjian's score	R/r	0.984**	0.986**
	P	0.0001	0.0001

Correlation analysis, r; *Significant at the 0.01 level (2-tailed).

The relationship between the scores obtained and Demirjian's scores in Chinese males when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.4a** and **4.4b**, respectively.

In a similar vein, the relationship between the scores obtained and Demirjian's scores in Chinese females when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.4c** and **4.4d**, respectively.

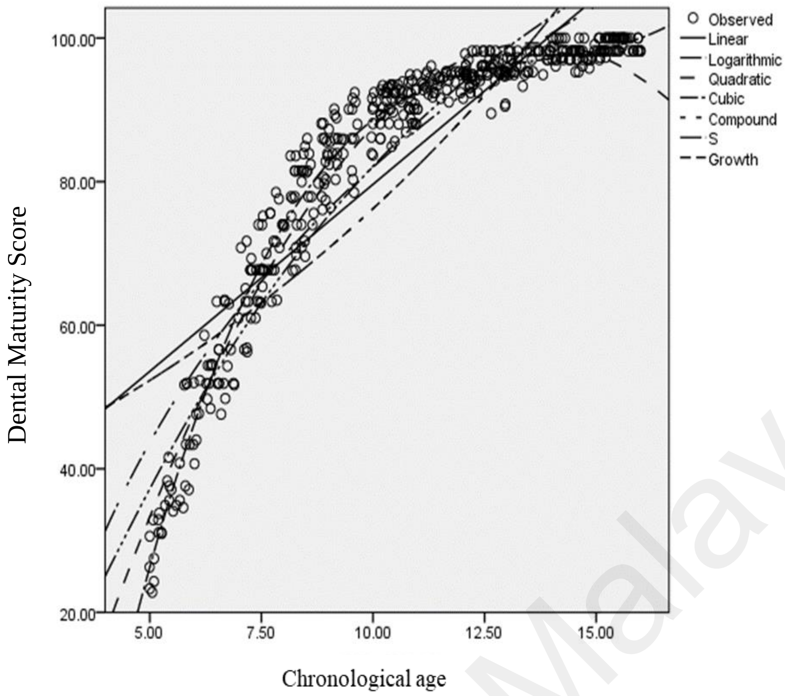

Figure 4.4a: Distribution of score sums based on Demirjian's scores plotted against median values of obtained scores for Chinese males by using regression analysis

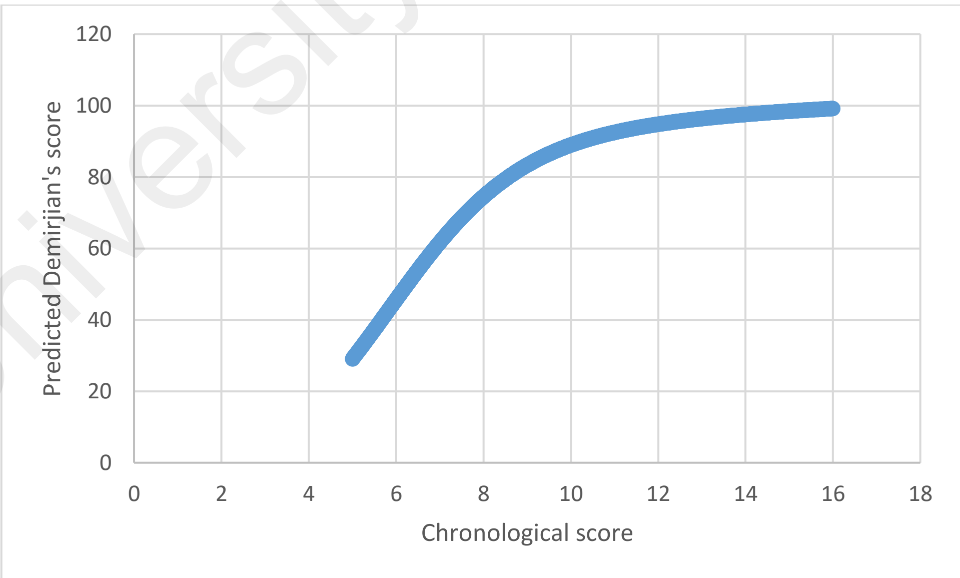

Figure 4.4b: Distribution of score sums based on Demirjian's scores plotted against median values of obtained scores for Chinese males following treatment of data with ANN

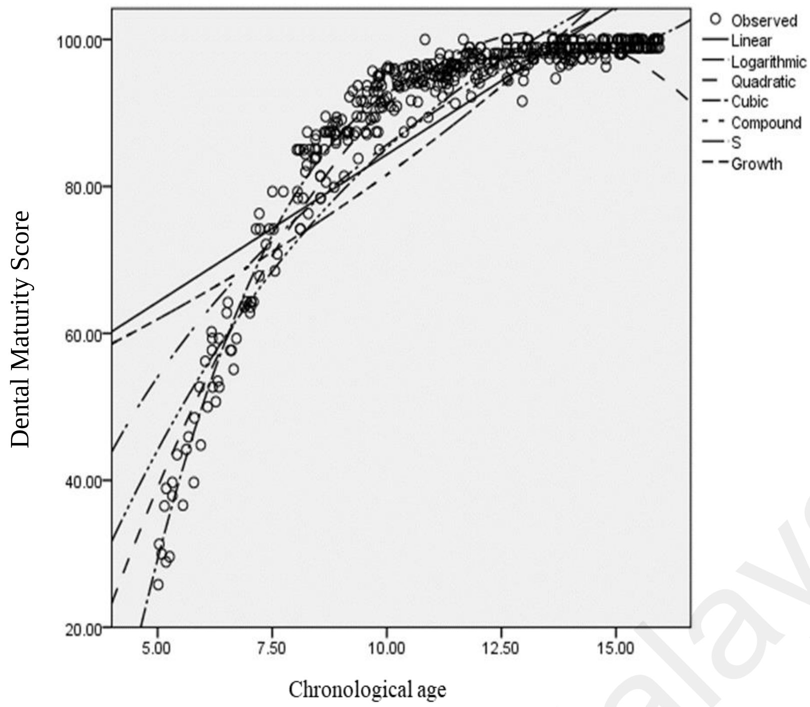

Figure 4.4c: Distribution of score sums based on Demirjian's scores plotted against median values of obtained scores for Chinese females by using regression analysis

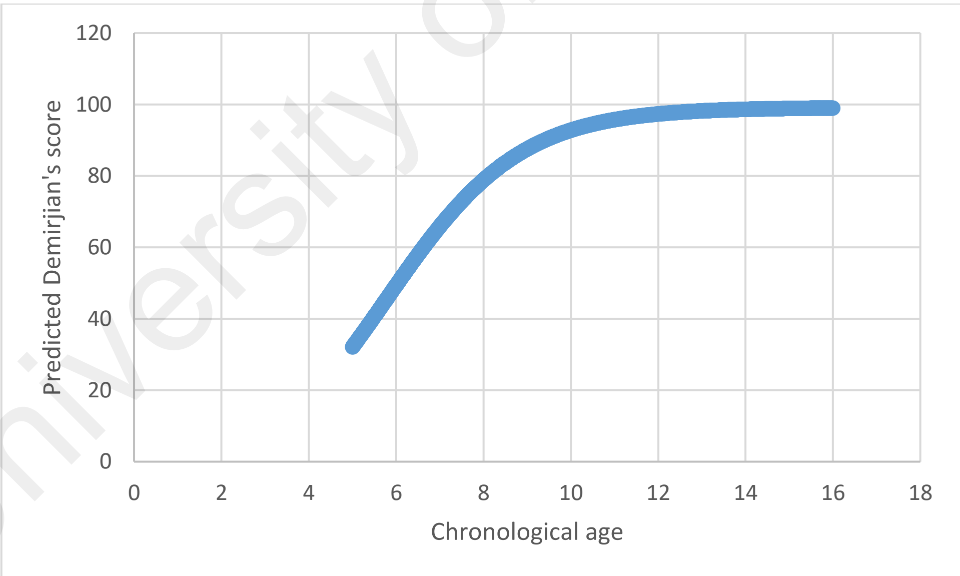

Figure 4.4d: Distribution of score sums based on Demirjian's scores plotted against median values of obtained scores for Chinese females following treatment of data with ANN

With ANN processing, there was 1 hidden layer consisting of 3 subunits in Chinese males and 1 subunit in females that connected the input (CA) to the output (score) (**Figures 4.5a** and **4.5b**, respectively).

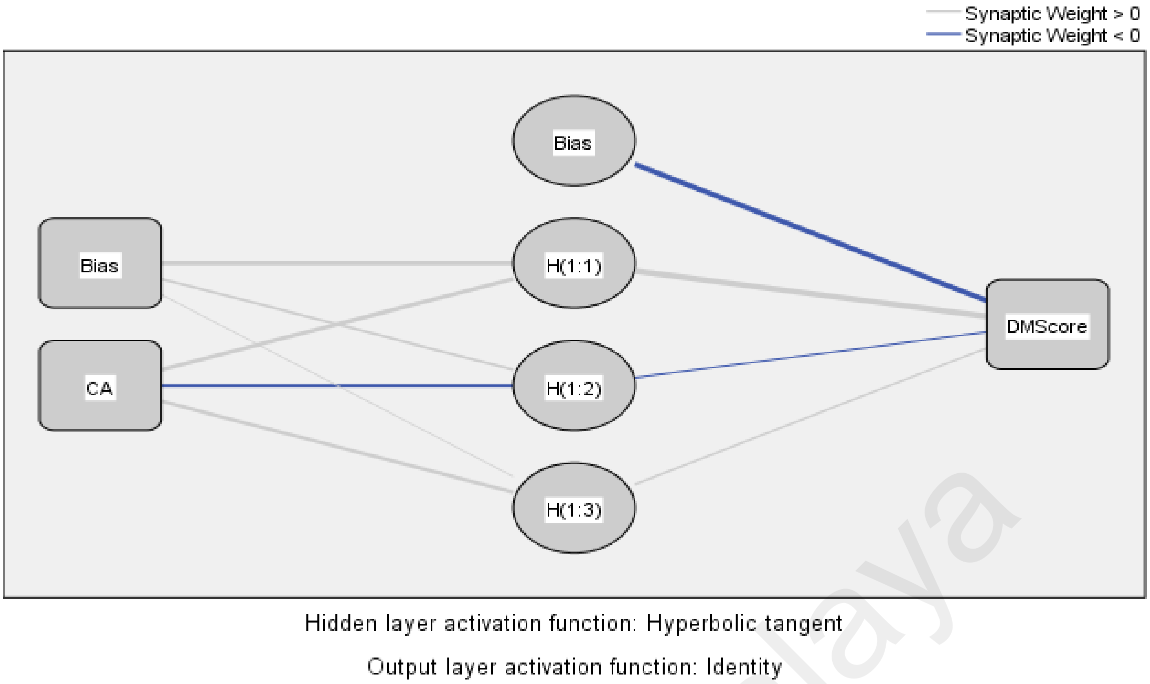

Figure 4.5a: Relationship between chronological age (CA) and Demirjian's score (DMScore) in Chinese males based on the 7-tooth method. H: hidden layer.

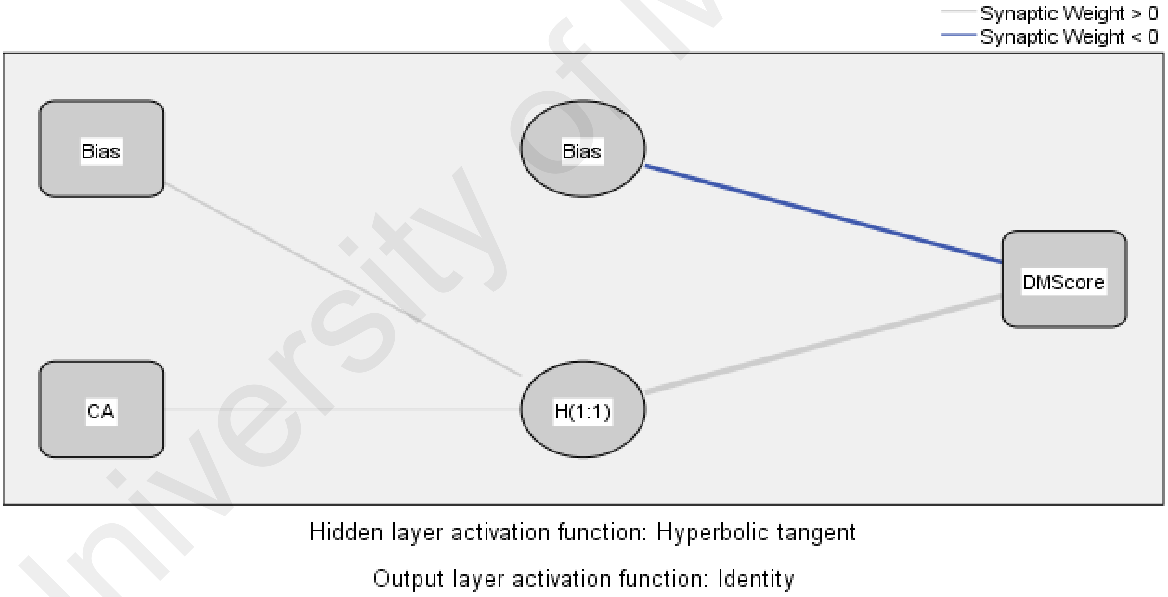

Figure 4.5b: Relationship between chronological age (CA) and Demirjian's score (DMScore) in Chinese females based on the 7-tooth method. H: hidden layer.

Following treatment of data with ANN, the overall difference between CA and NDA in Chinese using paired-samples t-test was not significant when values were pooled together (**Table 4.15**). The difference was 0.002 years, equivalent to 0.02 months or within a day in males, whereas in females, it was 0.028 years, which was equivalent to 0.34 months or about 10 days. The minimal difference observed post-

ANN contrasted with the pre-ANN counterpart which exceeded 4 months' difference in Chinese subjects (**Table 4.13**).

Table 4.15: Summary for comparison of chronological age and new dental age (determined by using ANN) in Chinese

Gender	(n)	CA	NDA	NDA-CA	*t*	p
Male	483	10.84 ± 3.08	10.84 ± 3.13	0.002 ± 0.78	0.047	0.963*
Female	449	11.57 ± 2.91	11.60 ± 3.10	0.028 ± 1.11	0.537	0.591*

Values are mean ± SD. CA: Chronological age. NDA: New dental age. Paired samples t-test, p>0.05.

Furthermore, when the overall data after being subjected to ANN analysis was sliced by age, the difference for each category of age was also not significant for males and females (**Tables 4.16a** and **4.16b**, respectively).

Table 4.16a: Comparison of chronological age and new dental age as determined by using ANN in Chinese males

Age	N	CA		NDA		NDA-CA		95 % CI		*t*	p*
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	32	5.47	0.32	5.49	0.43	0.03	0.25	-0.06	0.12	0.58	0.57
6.0-6.9	31	6.48	0.27	6.48	0.35	0.01	0.30	-0.10	0.12	0.13	0.90
7.0-7.9	45	7.51	0.27	7.49	0.42	-0.02	0.35	-0.12	0.08	-0.38	0.70
8.0-8.9	49	8.54	0.28	8.56	0.61	0.02	0.54	-0.14	0.17	0.24	0.81
9.0-9.9	31	9.41	0.30	9.54	0.73	0.13	0.69	-0.12	0.38	1.05	0.30
10.0-10.9	63	10.52	0.30	10.58	0.71	0.05	0.71	-0.13	0.23	0.59	0.56
11.0-11.9	34	11.47	0.28	11.56	0.65	0.09	0.61	-0.12	0.30	0.87	0.39
12.0-12.9	63	12.46	0.31	12.44	1.13	-0.02	1.15	-0.31	0.27	-0.14	0.89
13.0-13.9	34	13.45	0.31	13.49	1.16	0.03	1.09	-0.35	0.41	0.18	0.86
14.0-14.9	46	14.47	0.28	14.39	1.07	-0.08	1.15	-0.42	0.26	-0.48	0.64
15.0-15.9	55	15.47	0.29	15.34	0.72	-0.12	0.75	-0.33	0.08	-1.24	0.22

CA: Chronological age. NDA: New dental age. Paired samples t-test, p>0.05.

Table 4.16b: Comparison of chronological age and new dental age as determined by using ANN in Chinese females

Age	N	CA		DA		NDA-CA		95 % CI		*t/z*	p*
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9[a]	17	5.43	0.31	5.43	0.37	0.00	0.20	-0.10	0.10	-0.02	0.98
6.0-6.9[a]	18	6.42	0.27	6.49	0.27	0.07	0.24	-0.05	0.19	-0.76	0.45
7.0-7.9[a]	16	7.30	0.24	7.36	0.42	0.06	0.31	-0.10	0.23	-0.57	0.57
8.0-8.9	44	8.50	0.29	8.59	0.45	0.09	0.37	-0.03	0.20	1.54	0.13
9.0-9.9	48	9.56	0.29	9.62	0.69	0.05	0.58	-0.11	0.22	0.65	0.52
10.0-10.9	43	10.52	0.29	10.65	1.07	0.13	1.04	-0.19	0.45	0.85	0.40
11.0-11.9	55	11.48	0.27	11.42	1.25	-0.06	1.16	-0.37	0.26	-0.38	0.71
12.0-12.9	41	12.51	0.31	12.47	1.68	-0.04	1.68	-0.57	0.49	-0.15	0.88
13.0-13.9	50	13.54	0.31	13.85	1.73	0.31	1.71	-0.18	0.79	1.28	0.21
14.0-14.9	47	14.48	0.29	14.46	1.48	-0.02	1.43	-0.44	0.40	-0.08	0.93
15.0-15.9	17	15.46	0.29	15.29	0.91	-0.16	0.87	-0.37	0.04	-1.58	0.12

CA: Chronological age. NDA: New dental age. Paired samples t-test, p>0.05.
a: Based on Wilcoxon test due to small sample size.

Thus, based on the data that was subjected to ANN analysis, dental scores that accurately predicted the CA were generated for males and females respectively (**Tables 4.17** and **4.18**).

Table 4.17: Scores calculated with ANN and dental age scales for Chinese males

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	29.06	9	83.31	13	96.34
5.1	30.64	9.1	84	13.1	96.47
5.2	32.25	9.2	84.66	13.2	96.6
5.3	33.88	9.3	85.28	13.3	96.72
5.4	35.53	9.4	85.88	13.4	96.84
5.5	37.2	9.5	86.45	13.5	96.96
5.6	38.88	9.6	87	13.6	97.07
5.7	40.57	9.7	87.52	13.7	97.18
5.8	42.26	9.8	88.02	13.8	97.29
5.9	43.95	9.9	88.49	13.9	97.4
6	45.64	10	88.94	14	97.5
6.1	47.33	10.1	89.37	14.1	97.6
6.2	49.01	10.2	89.78	14.2	97.7
6.3	50.67	10.3	90.17	14.3	97.79
6.4	52.32	10.4	90.55	14.4	97.89
6.5	53.94	10.5	90.91	14.5	97.98
6.6	55.55	10.6	91.25	14.6	98.07
6.7	57.13	10.7	91.57	14.7	98.16
6.8	58.68	10.8	91.89	14.8	98.24
6.9	60.2	10.9	92.18	14.9	98.33
7	61.69	11	92.47	15	98.41
7.1	63.14	11.1	92.74	15.1	98.49
7.2	64.56	11.2	93.01	15.2	98.57
7.3	65.94	11.3	93.26	15.3	98.64
7.4	67.29	11.4	93.5	15.4	98.72
7.5	68.59	11.5	93.73	15.5	98.79
7.6	69.85	11.6	93.95	15.6	98.87
7.7	71.07	11.7	94.16	15.7	98.94
7.8	72.25	11.8	94.37	15.8	99.01
7.9	73.39	11.9	94.57	15.9	99.08
8	74.48	12	94.76	16	99.14
8.1	75.54	12.1	94.94		
8.2	76.56	12.2	95.12		
8.3	77.53	12.3	95.29		
8.4	78.47	12.4	95.45		
8.5	79.37	12.5	95.61		
8.6	80.23	12.6	95.77		
8.7	81.05	12.7	95.92		
8.8	81.84	12.8	96.06		
8.9	82.59	12.9	96.2		

Table 4.18: Scores calculated with ANN and dental age scales for Chinese females

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	32.11	9	87.57	13	98.22
5.1	33.77	9.1	88.23	13.1	98.28
5.2	35.45	9.2	88.86	13.2	98.33
5.3	37.16	9.3	89.45	13.3	98.38
5.4	38.88	9.4	90.02	13.4	98.43
5.5	40.61	9.5	90.55	13.5	98.48
5.6	42.36	9.6	91.05	13.6	98.52
5.7	44.11	9.7	91.53	13.7	98.56
5.8	45.87	9.8	91.98	13.8	98.6
5.9	47.62	9.9	92.41	13.9	98.63
6	49.37	10	92.81	14	98.66
6.1	51.12	10.1	93.19	14.1	98.7
6.2	52.85	10.2	93.55	14.2	98.72
6.3	54.57	10.3	93.89	14.3	98.75
6.4	56.26	10.4	94.21	14.4	98.78
6.5	57.94	10.5	94.51	14.5	98.8
6.6	59.59	10.6	94.79	14.6	98.82
6.7	61.21	10.7	95.06	14.7	98.84
6.8	62.8	10.8	95.31	14.8	98.86
6.9	64.36	10.9	95.54	14.9	98.88
7	65.89	11	95.77	15	98.9
7.1	67.37	11.1	95.98	15.1	98.91
7.2	68.82	11.2	96.17	15.2	98.93
7.3	70.23	11.3	96.36	15.3	98.94
7.4	71.59	11.4	96.53	15.4	98.96
7.5	72.91	11.5	96.69	15.5	98.97
7.6	74.19	11.6	96.84	15.6	98.98
7.7	75.42	11.7	96.99	15.7	98.99
7.8	76.61	11.8	97.12	15.8	99
7.9	77.76	11.9	97.25	15.9	99.01
8	78.86	12	97.37	16	99.02
8.1	79.92	12.1	97.48		
8.2	80.93	12.2	97.58		
8.3	81.9	12.3	97.68		
8.4	82.83	12.4	97.77		
8.5	83.72	12.5	97.86		
8.6	84.57	12.6	97.94		
8.7	85.37	12.7	98.02		
8.8	86.14	12.8	98.09		
8.9	86.87	12.9	98.16		

4.2.1.3 Dental age estimation in the Indians using original Demirjian's method 1973

A total of 782 Indian samples were analysed (**Table 4.19**).

Table 4.19: Distribution of Indian subjects based on age and gender

Chronological age (years)	Male (%)	Female (%)	Total (%)
5.0-5.9	13 (3.25)	9 (2.36)	22 (2.81)
6.0-6.9	19 (4.75)	15 (3.93)	34 (4.35)
7.0-7.9	23 (5.75)	11 (2.88)	34 (4.35)
8.0-8.9	29 (7.25)	36 (9.42)	65 (8.31)
9.0-9.9	33 (8.25)	33 (8.64)	66 (8.44)
10.0-10.9	41 (10.25)	43 (11.26)	84 (10.74)
11.0-11.9	50 (12.5)	45 (11.78)	95 (12.15)
12.0-12.9	49 (12.25)	46 (12.04)	95 (12.15)
13.0-13.9	45 (11.25)	54 (14.14)	99 (12.66)
14.0-14.9	49 (12.25)	48 (12.57)	97 (12.40)
15.0-15.9	49 (12.25)	42 (10.99)	91 (11.64)
Total	400 (100.00)	382 (100.00)	782 (100.00)

Comparison between CA and DA in Indian males showed significant differences in all the age groups (**Table 4.20a**). This finding is thus similar across all ethnicities.

Table 4.20a: Comparison of chronological age and dental age as determined by using original Demirjian's standards in Indian males

Age	N	CA		DA		DA-CA		95 % CI		*t/z*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9[a]	13	5.52	0.26	6.28	0.66	0.76	0.49	0.47	1.06	-2.97	0.00*
6.0-6.9[a]	19	6.58	0.31	7.45	0.34	0.87	0.24	0.76	0.98	-3.82	0.00*
7.0-7.9[a]	23	7.50	0.32	8.05	0.33	0.55	0.21	0.46	0.65	-4.19	0.00*
8.0-8.9	29	8.53	0.27	8.79	0.63	0.27	0.48	0.09	0.45	3.01	0.01*
9.0-9.9	33	9.54	0.32	9.83	0.75	0.29	0.71	0.04	0.54	2.34	0.03*
10.0-10.9	41	10.49	0.29	10.91	0.90	0.42	0.83	0.16	0.68	3.26	0.00*
11.0-11.9	50	11.53	0.28	11.92	1.41	0.40	1.34	0.02	0.78	2.09	0.04*
12.0-12.9	49	12.44	0.31	12.99	1.38	0.55	1.39	0.15	0.95	2.76	0.01*
13.0-13.9	45	13.56	0.35	14.26	1.46	0.70	1.26	0.32	1.08	3.73	0.00*
14.0-14.9	49	14.50	0.30	15.50	0.95	1.00	0.96	0.73	1.28	7.32	0.00*
15.0-15.9	49	15.51	0.29	15.96	0.08	0.45	0.27	0.37	0.53	11.67	0.00*

CA: Chronological age. DA: Dental age. Paired samples t-test; *Statistically significant at the 0.05 level.
a: Based on Wilcoxon test due to small sample size.

However, comparison between CA and DA in Indian females showed significant differences in all age groups except for the 8- and 15-year-olds (**Table 4.20b**).

Table 4.20b: Comparison of chronological age and dental age as determined by using original Demirjian's standards in Indian females

Age	N	CA		DA		DA-CA		95 % CI		*t/z*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9[a]	9	5.44	0.35	6.16	0.77	0.71	0.48	0.34	1.08	-2.67	0.00*
6.0-6.9[a]	15	6.55	0.29	7.35	0.24	0.81	0.14	0.73	0.88	-3.41	0.00*
7.0-7.9[a]	11	7.49	0.29	7.83	0.27	0.34	0.16	0.23	0.45	-2.93	0.00*
8.0-8.9	36	8.55	0.31	8.61	0.53	0.06	0.37	-0.07	0.19	0.95	0.35
9.0-9.9	33	9.55	0.31	9.96	1.04	0.42	0.94	0.08	0.75	2.53	0.02*
10.0-10.9	43	10.50	0.28	10.97	0.96	0.46	0.94	0.17	0.75	3.23	0.00*
11.0-11.9	45	11.51	0.27	12.09	0.99	0.58	1.01	0.27	0.88	3.82	0.00*
12.0-12.9	46	12.45	0.26	13.19	1.16	0.73	1.07	0.42	1.05	4.65	0.00*
13.0-13.9	54	13.55	0.27	14.09	1.07	0.54	1.07	0.25	0.83	3.71	0.00*
14.0-14.9	48	14.47	0.26	14.79	0.98	0.31	0.96	0.03	0.59	2.24	0.03*
15.0-15.9	42	15.50	0.30	15.60	0.64	0.10	0.67	-0.11	0.30	0.94	0.35

CA: Chronological age. DA: Dental age. Paired samples t-test, *Statistically significant at the 0.05 level.
a: Based on Wilcoxon test due to small sample size.

Overall, the difference between CA and DA in Indian subjects was significant when values were pooled together (**Table 4.21**). The difference represented over-estimation by 0.56 years, equivalent to 6.7 months in males, whereas in females it was 0.43 years, which was equivalent to 5.2 months.

Table 4.21: Summary for comparison of chronological age and dental age (determined by using original Demirjian's method) in Indians

Gender	N	CA	DA	DA-CA	*t*	p
Male	400	11.57± 2.84	12.13 ±3.05	0.56± 0.97	11.532	0.0001*
Female	382	11.71± 2.68	12.14± 2.78	0.43 ± 0.90	9.388	0.0001*

CA: Chronological age. DA: Dental age. Values are mean ± SD. Paired samples t-test. *Significant at the 0.05 level.

The correlation between CA and Demirjian's scores was very high (**Table 4.22**). However, although the correlation was high, the difference between CA and scores was significant.

Table 4.22: Correlation between chronological age, Demirjian's scores and predicted values for Demirjian's scores in Indians

		Chronological age	
		Male	**Female**
Demirjian's score	r	0.980**	0.985**
	p	0.0001	0.0001
Predicted value for Demirjian's score	R/r	0.980**	0.985**
	P	0.0001	0.0001

Correlation analysis, r; *Significant at the 0.01 level (2-tailed).

The relationship between the scores obtained and Demirjian's scores in Indian males when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.6a** and **4.6b**, respectively.

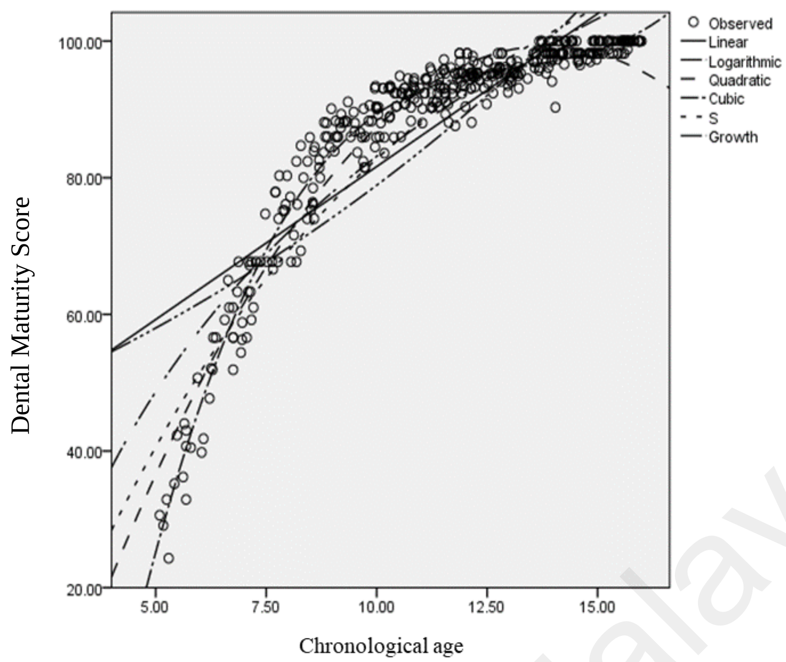

Figure 4.6a: Distribution of score sums based on Demirjian's scores plotted against median values of obtained scores for Indian males by using regression analysis

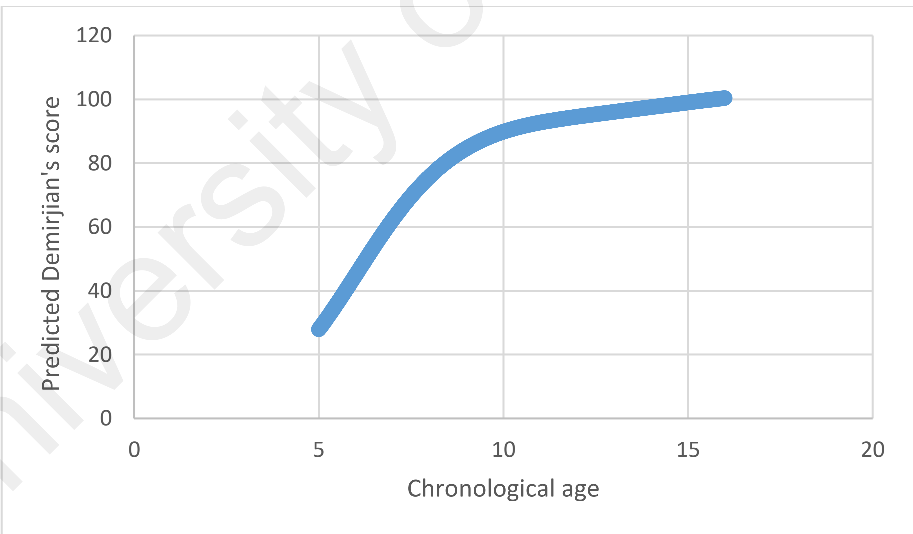

Figure 4.6b: Distribution of score sums based on Demirjian's scores plotted against median values of obtained scores for Indian males following treatment of data with ANN

The relationship between the scores obtained and Demirjian's scores in Indian females when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.6c** and **4.6d**, respectively.

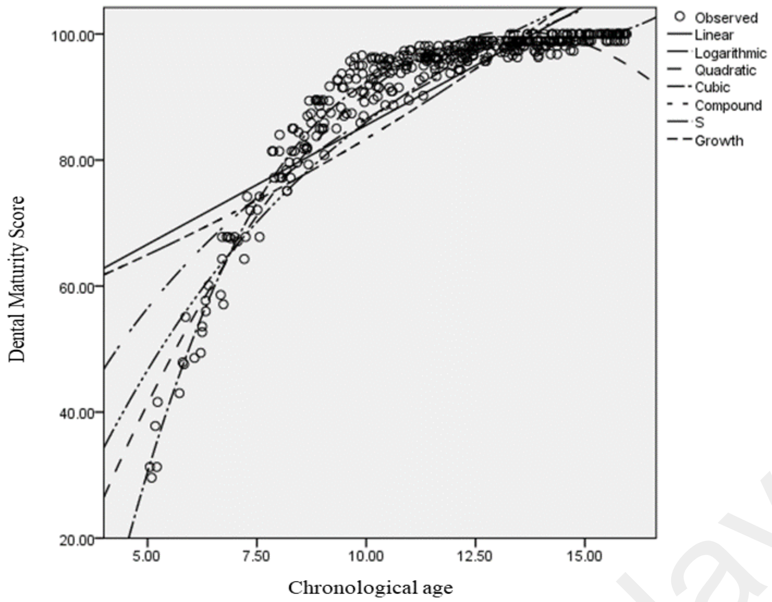

Figure 4.6c: Distribution of score sums based on Demirjian's scores plotted against median values of obtained scores for Indian females by using regression analysis

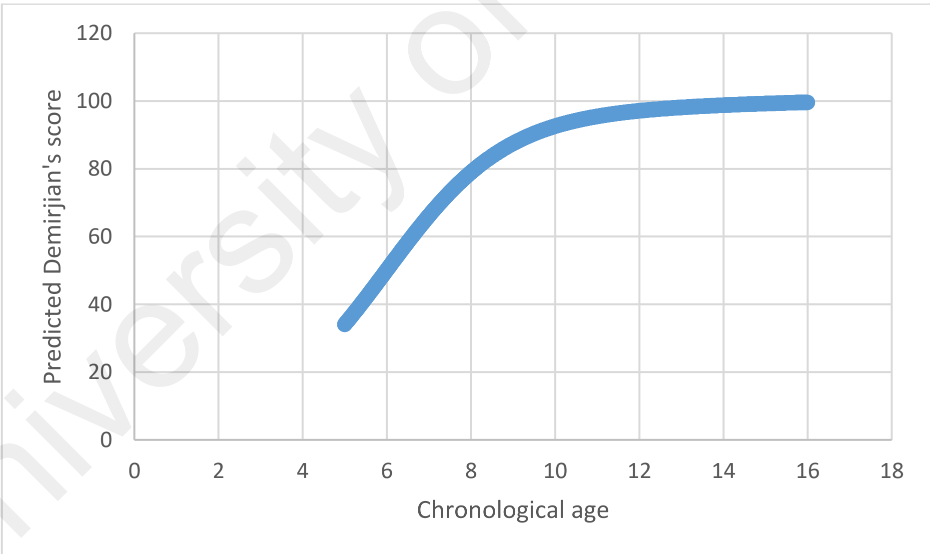

Figure 4.6d: Distribution of score sums based on Demirjian's scores plotted against median values of obtained scores for Indian females following treatment of data with ANN

With both the Indian male and female samples, there is 1 hidden layer consisting of 3 subunits in male and 3 subunits in female that connect the input (CA) to the output (score), after ANN processing (**Figures 4.7a** and **4.7b**).

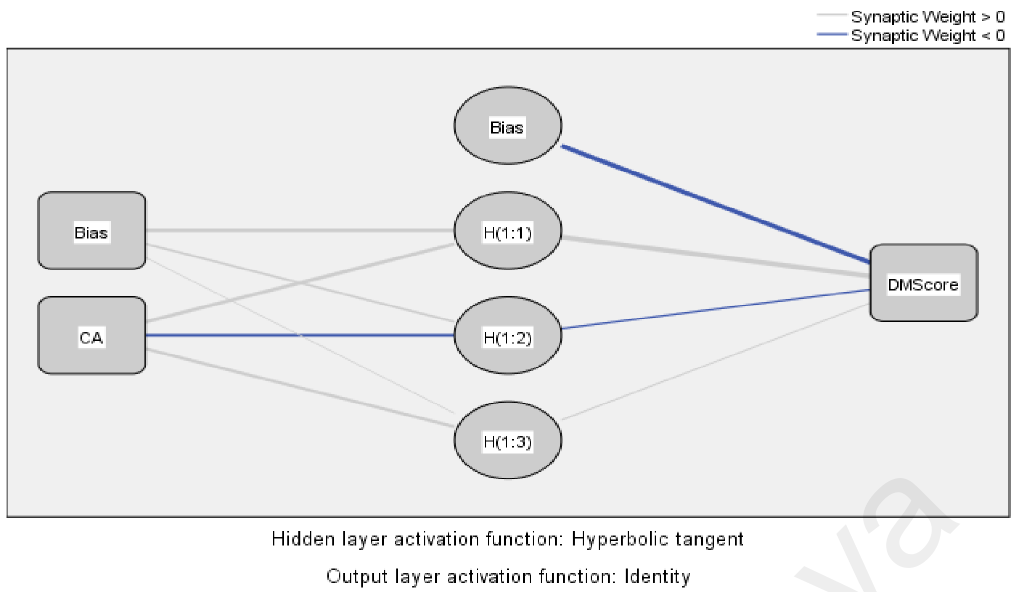

Figure 4.7a: Relationship between chronological age (CA) and Demirjian's score (DMScore) in Indian males based on the 7-tooth method. H: hidden layer.

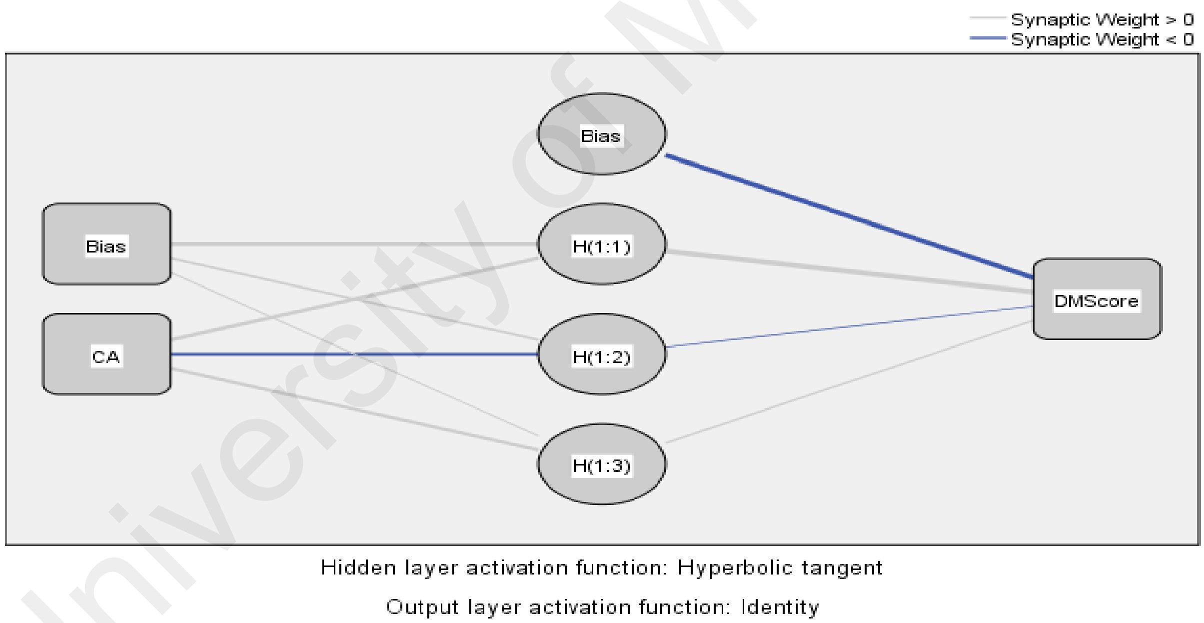

Figure 4.7b: Relationship between chronological age (CA) and Demirjian's score (DMScore) in Indian females based on the 7-tooth method. H: hidden layer.

After treatment of data with ANN, the overall difference between CA and NDA in the Indian children using paired-samples t-test was not significant when values were pooled together (**Table 4.23**). The difference was 0.039 years, equivalent to 0.47 months or 14 days in males, whereas in females, it was 0.032 years, which was equivalent to 0.38 months or about 12 days. Again, as with the other ethnicities, these differences were minimal compared to pre-ANN whereby the overall age of Indian children was over-estimated by more than 5 months (**Table 4.21**).

Table 4.23: Summary for comparison of chronological age and new dental age (determined by using ANN) in Indians

Sex	N	CA	NDA	NDA-CA	*t*	p
Male	400	11.57± 2.84	11.61 ± 2.97	0.039± 0.86	0.905	0.366*
Female	382	11.71± 2.68	11.74± 2.82	0.032 ± 0.93	0.675	0.500*

CA: Chronological age. NDA: New dental age. Paired samples t-test. *Not significant at the 0.05 level.

When the overall data after being subjected to ANN analysis was sliced by age, the difference for each category of age was also not significant for the Indians (**Tables 4.24a** and **4.24b**), similar to Malays and Chinese.

Table 4.24a: Comparison of chronological age and new dental age as determined by using ANN in Indian males

Age	N	CA		DA		DA-CA		95 % CI		*t/z*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9[a]	13	5.52	0.26	5.57	0.39	0.05	0.23	-0.09	0.19	-0.94	0.35
6.0-6.9[a]	19	6.58	0.31	6.63	0.42	0.05	0.30	-0.09	0.19	-0.64	0.52
7.0-7.9[a]	23	7.50	0.32	7.56	0.51	0.06	0.32	-0.08	0.20	-0.91	0.36
8.0-8.9	29	8.53	0.27	8.53	0.70	0.01	0.54	-0.20	0.21	0.07	0.94
9.0-9.9	33	9.54	0.32	9.57	0.64	0.02	0.63	-0.20	0.25	0.22	0.83
10.0-10.9	41	10.49	0.29	10.60	0.85	0.10	0.77	-0.14	0.35	0.87	0.39
11.0-11.9	50	11.53	0.28	11.52	1.25	-0.01	1.19	-0.35	0.33	-0.06	0.95
12.0-12.9	49	12.44	0.31	12.47	1.14	0.02	1.15	-0.31	0.35	0.14	0.89
13.0-13.9	45	13.56	0.35	13.59	1.26	0.03	1.08	-0.29	0.35	0.20	0.85
14.0-14.9	49	14.50	0.30	14.65	1.01	0.15	1.02	-0.14	0.44	1.02	0.31
15.0-15.9	49	15.51	0.29	15.47	0.51	-0.04	0.49	-0.18	0.10	-0.59	0.56

Paired samples t-test, p>0.05. a: Based on Wilcoxon test due to small sample size.

Table 4.24b: Comparison of chronological age and new dental age as determined by using ANN in Indian females

Age	N	CA		DA		DA-CA		95 % CI		*t/z*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9[a]	9	5.44	0.35	5.48	0.46	0.04	0.20	-0.12	0.19	-0.29	0.77
6.0-6.9[a]	15	6.55	0.29	6.61	0.44	0.06	0.22	-0.06	0.18	-1.02	0.31
7.0-7.9[a]	11	7.49	0.29	7.51	0.46	0.02	0.27	-0.17	0.20	0.00	1.00
8.0-8.9	36	8.55	0.31	8.53	0.52	-0.02	0.35	-0.14	0.10	-0.35	0.73
9.0-9.9	33	9.55	0.31	9.72	0.86	0.17	0.77	-0.10	0.44	1.29	0.21
10.0-10.9	43	10.50	0.28	10.54	0.79	0.04	0.78	-0.20	0.28	0.35	0.73
11.0-11.9	45	11.51	0.27	11.49	0.85	-0.03	0.88	-0.29	0.24	-0.20	0.85
12.0-12.9	46	12.45	0.26	12.58	1.21	0.12	1.12	-0.21	0.46	0.76	0.45
13.0-13.9	54	13.55	0.27	13.58	1.29	0.03	1.29	-0.32	0.38	0.18	0.86
14.0-14.9	48	14.47	0.26	14.44	1.25	-0.03	1.22	-0.39	0.32	-0.18	0.86
15.0-15.9	42	15.50	0.30	15.49	0.82	-0.01	0.83	-0.27	0.24	-0.12	0.91

Paired samples t-test, p>0.05. a: Based on Wilcoxon test due to small sample size.

Thus, based on the data that was subjected to ANN analysis, dental scores that accurately predicted the CA were generated (**Tables 4.25** and **4.26**), for Indian males and females respectively.

Table 4.25: Scores calculated with ANN and dental age scales for Indian males

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	27.82	9	84.6	13	96.03
5.1	29.39	9.1	85.27	13.1	96.18
5.2	31	9.2	85.89	13.2	96.33
5.3	32.64	9.3	86.49	13.3	96.48
5.4	34.32	9.4	87.05	13.4	96.63
5.5	36.04	9.5	87.58	13.5	96.78
5.6	37.77	9.6	88.08	13.6	96.92
5.7	39.53	9.7	88.55	13.7	97.07
5.8	41.31	9.8	88.99	13.8	97.22
5.9	43.1	9.9	89.41	13.9	97.37
6	44.9	10	89.8	14	97.51
6.1	46.7	10.1	90.17	14.1	97.66
6.2	48.49	10.2	90.52	14.2	97.81
6.3	50.28	10.3	90.85	14.3	97.96
6.4	52.06	10.4	91.16	14.4	98.1
6.5	53.82	10.5	91.45	14.5	98.25
6.6	55.55	10.6	91.73	14.6	98.39
6.7	57.26	10.7	91.99	14.7	98.54
6.8	58.94	10.8	92.23	14.8	98.68
6.9	60.58	10.9	92.47	14.9	98.83
7	62.19	11	92.69	15	98.97
7.1	63.75	11.1	92.9	15.1	99.11
7.2	65.27	11.2	93.11	15.2	99.25
7.3	66.75	11.3	93.3	15.3	99.4
7.4	68.18	11.4	93.49	15.4	99.54
7.5	69.56	11.5	93.67	15.5	99.68
7.6	70.9	11.6	93.85	15.6	99.81
7.7	72.18	11.7	94.02	15.7	99.95
7.8	73.41	11.8	94.19	15.8	100.09
7.9	74.6	11.9	94.35	15.9	100.23
8	75.74	12	94.51	16	100.36
8.1	76.82	12.1	94.67		
8.2	77.86	12.2	94.83		
8.3	78.86	12.3	94.98		
8.4	79.81	12.4	95.13		
8.5	80.71	12.5	95.29		
8.6	81.57	12.6	95.44		
8.7	82.39	12.7	95.59		
8.8	83.17	12.8	95.74		
8.9	83.9	12.9	95.89		

Table 4.26: Scores calculated with ANN and dental age scales for Indian females

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	34.08	9	87.49	13	98.12
5.1	35.58	9.1	88.13	13.1	98.2
5.2	37.11	9.2	88.74	13.2	98.28
5.3	38.67	9.3	89.32	13.3	98.35
5.4	40.26	9.4	89.87	13.4	98.42
5.5	41.87	9.5	90.39	13.5	98.48
5.6	43.5	9.6	90.88	13.6	98.55
5.7	45.14	9.7	91.34	13.7	98.61
5.8	46.8	9.8	91.78	13.8	98.67
5.9	48.46	9.9	92.19	13.9	98.73
6	50.13	10	92.58	14	98.79
6.1	51.79	10.1	92.95	14.1	98.84
6.2	53.45	10.2	93.3	14.2	98.89
6.3	55.11	10.3	93.63	14.3	98.95
6.4	56.75	10.4	93.94	14.4	99
6.5	58.37	10.5	94.24	14.5	99.04
6.6	59.98	10.6	94.51	14.6	99.09
6.7	61.56	10.7	94.77	14.7	99.14
6.8	63.12	10.8	95.02	14.8	99.18
6.9	64.65	10.9	95.25	14.9	99.23
7	66.14	11	95.47	15	99.27
7.1	67.6	11.1	95.68	15.1	99.31
7.2	69.03	11.2	95.88	15.2	99.35
7.3	70.41	11.3	96.07	15.3	99.39
7.4	71.76	11.4	96.24	15.4	99.43
7.5	73.06	11.5	96.41	15.5	99.46
7.6	74.32	11.6	96.57	15.6	99.5
7.7	75.54	11.7	96.72	15.7	99.53
7.8	76.72	11.8	96.86	15.8	99.57
7.9	77.85	11.9	97	15.9	99.6
8	78.93	12	97.12	16	99.64
8.1	79.98	12.1	97.25		
8.2	80.97	12.2	97.36		
8.3	81.93	12.3	97.47		
8.4	82.84	12.4	97.58		
8.5	83.72	12.5	97.68		
8.6	84.55	12.6	97.78		
8.7	85.34	12.7	97.87		
8.8	86.09	12.8	97.96		
8.9	86.81	12.9	98.04		

4.2.2 Dental age estimation using modified Chaillet & Demirjian's method 2004

In this section, the samples that were analysed were extended to include those children aged 5-18 years old. Thus, the sample size was larger than that analysed using Demirjian's original method (1973). Generally, Malays represented the largest group followed by Chinese and then Indians, with males and females for each ethnicity being represented in approximately equal proportions of 50% of each (**Table 4.27**).

Table 4.27: Demographics of study subjects (5 – 18 years)

Ethnicity	Sex	N (%)	Total by ethnicity (%)
Malay	Male	792 (50.1)	1569 (41.2)
	Female	777 (49.5)	
Chinese	Male	614 (50.0)	1228 (32.2)
	Female	614 (50.0)	
Indian	Male	494 (48.7)	1015 (26.6)
	Female	521 (51.3)	
Total		3812 (100.0)	

4.2.2.1 Dental age estimation in Malays using modified Chaillet & Demirjian's method 2004

A total of 1569 Malay samples were analysed (**Table 4.28**).

Table 4.28: Distribution of Malay subjects by age and sex

Chronological age (years)	Male (%)	Female (%)	Total (%)
5.0-5.9	92 (11.62)	90 (11.58)	182 (11.60)
6.0-6.9	66 (8.33)	62 (7.98)	128 (8.16)
7.0-7.9	88 (11.11)	77 (9.91)	165 (10.52)
8.0-8.9	87 (10.98)	70 (9.01)	157 (10.01)
9.0-9.9	65 (8.21)	63 (8.11)	128 (8.16)
10.0-10.9	56 (7.07)	61 (7.85)	117 (7.46)
11.0-11.9	61 (7.70)	64 (8.24)	125 (7.97)
12.0-12.9	58 (7.32)	51 (6.56)	109 (6.95)
13.0-13.9	37 (4.67)	51 (6.56)	88 (5.61)
14.0-14.9	40 (5.05)	40 (5.15)	80 (5.10)
15.0-15.9	39 (4.92)	45 (5.79)	84 (5.35)
16.0-16.9	53 (6.69)	63 (8.11)	116 (7.39)
17.0-17.9	50 (6.31)	40 (5.15)	90 (5.74)
Total	792 (100.00)	777 (100.00)	1569 (100.00)

Comparison between CA and DA in Malay males showed significant differences in all age groups (**Table 4.29a**).

Table 4.29a: Comparison of chronological age and dental age as determined by using modified Demirjian's standards in Malay males

Age	N	CA		DA		DA-CA		95 % CI		*t*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	92	5.46	0.26	3.09	0.80	-2.36	0.72	-2.51	-2.22	-31.69	0.00*
6.0-6.9	66	6.48	0.27	4.20	0.69	-2.28	0.62	-2.43	-2.12	-29.72	0.00*
7.0-7.9	88	7.49	0.27	5.16	0.75	-2.33	0.70	-2.48	-2.19	-31.39	0.00*
8.0-8.9	87	8.46	0.29	6.21	0.82	-2.25	0.78	-2.41	-2.08	-26.77	0.00*
9.0-9.9	65	9.48	0.31	7.55	1.04	-1.92	0.98	-2.17	-1.68	-15.84	0.00*
10.0-10.9	56	10.43	0.28	8.63	1.02	-1.80	0.93	-2.05	-1.55	-14.44	0.00*
11.0-11.9	61	11.45	0.28	9.59	0.90	-1.86	0.89	-2.09	-1.64	-16.40	0.00*
12.0-12.9	58	12.46	0.31	10.57	0.99	-1.89	0.92	-2.13	-1.64	-15.56	0.00*
13.0-13.9	37	13.51	0.27	11.42	0.90	-2.09	0.86	-2.38	-1.81	-14.75	0.00*
14.0-14.9	40	14.56	0.29	12.67	0.98	-1.89	0.99	-2.21	-1.58	-12.09	0.00*
15.0-15.9	39	15.48	0.29	13.63	1.33	-1.85	1.19	-2.24	-1.46	-9.71	0.00*
16.0- 16.9	53	16.44	0.31	14.23	1.35	-2.21	1.29	-2.57	-1.86	-12.45	0.00*
17.0-17.9	50	17.47	0.30	15.62	0.81	-1.85	0.75	-2.07	-1.64	-17.53	0.00*

CA: Chronological age. DA: Dental age. Paired samples t-test. * Statistically significant at the 0.05 level.

Similarly, comparison between CA and DA in Malay females showed significant differences in all age groups (**Table 4.29b**).

Table 4.29b: Comparison of chronological age and dental age as determined by using modified Demirjian's standards in Malay females

Age	N	CA		DA		DA-CA		95 % CI		*t*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	90	5.48	0.28	2.80	0.77	-2.68	0.67	-2.82	-2.54	-37.72	0.00*
6.0-6.9	62	6.50	0.31	4.08	0.72	-2.43	0.65	-2.59	-2.26	-29.48	0.00*
7.0-7.9	77	7.50	0.30	4.92	0.74	-2.58	0.65	-2.73	-2.44	-34.70	0.00*
8.0-8.9	70	8.47	0.29	5.95	0.87	-2.52	0.85	-2.72	-2.32	-24.89	0.00*
9.0-9.9	63	9.50	0.27	7.00	0.82	-2.50	0.79	-2.70	-2.30	-25.16	0.00*
10.0-10.9	61	10.45	0.29	8.04	0.88	-2.41	0.86	-2.63	-2.19	-21.85	0.00*
11.0-11.9	64	11.49	0.29	9.15	1.14	-2.34	1.16	-2.63	-2.05	-16.13	0.00*
12.0-12.9	51	12.46	0.29	10.00	1.03	-2.46	1.00	-2.74	-2.18	-17.63	0.00*
13.0-13.9	51	13.44	0.29	10.70	0.87	-2.74	0.88	-2.99	-2.49	-22.16	0.00*
14.0-14.9	40	14.48	0.30	11.37	0.52	-3.11	0.54	-3.28	-2.94	-36.63	0.00*
15.0-15.9	45	15.45	0.30	11.95	0.81	-3.50	0.77	-3.74	-3.27	-30.49	0.00*
16.0- 16.9	63	16.49	0.28	12.56	0.97	-3.94	0.94	-4.17	-3.70	-33.41	0.00*
17.0-17.9	40	17.61	0. 28	13.80	1.35	-3.81	1.30	-4.23	-3.40	-18.56	0.00*

CA: Chronological age. DA: Dental age. Paired samples t-test. * Statistically significant at the 0.05 level.

Overall, the difference between CA and DA in Malays when the modified Demirjian's method was used was significant when values were pooled together (**Table 4.30**). The difference represented under-estimation by 2.09 years in males and 2.79 years in females.

Table 4.30: Summary for comparison of chronological age and dental age (determined by using the modified Demirjian's standards) in Malays

Gender	N	CA	DA	DA-CA	*t*	p
Male	792	10.58 ± 3.77	8.49 ± 4.01	-2.09 ± 0.90	-65.23	0.0001*
Female	777	10.78 ± 3.77	8.00 ± 3.5	-2.79 ± 0.99	-78.382	0.0001*

CA: Chronological age. DA: Dental age. Paired samples t-test. *Statistically significant at the 0.05 level.

The correlation between CA and Demirjian's scores was very high (**Table 4.31**). However, although the correlation was high, the difference between CA and scores was significant.

Table 4.31: Correlation between chronological age, modified Demirjian's scores and predicted values for modified Demirjian's scores in Malays

		Chronological age	
		Male	**Female**
Modified Demirjian's score	r	0.978**	0.975**
	p	0.0001	0.0001
Predicted value for Demirjian's modified score	R/r	0.978**	0.975**
	P	0.0001	0.0001

Correlation analysis, r; *Significant at the 0.01 level (2-tailed).

The relationship between the scores obtained and modified Demirjian's scores in Malay males when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.8a** and **4.8b**, respectively.

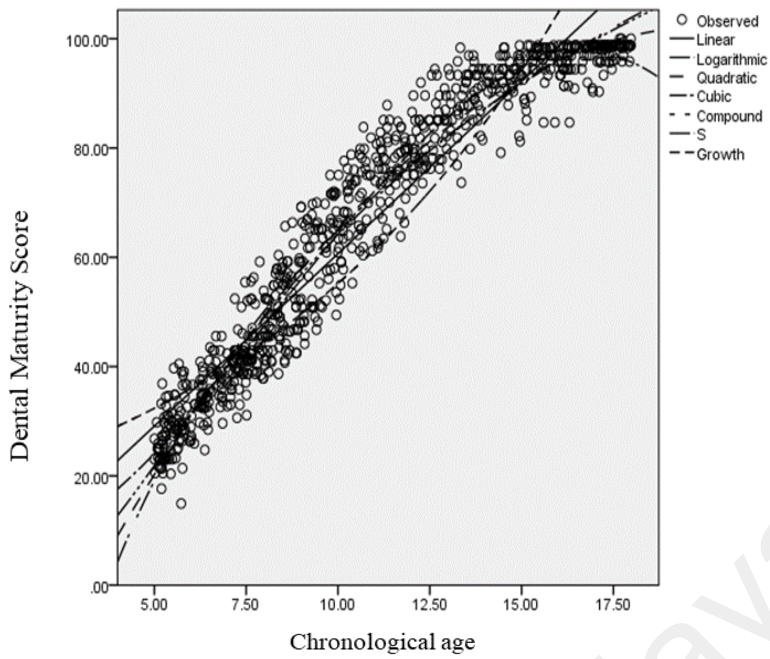

Figure 4.8a: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Malay males by using regression analysis

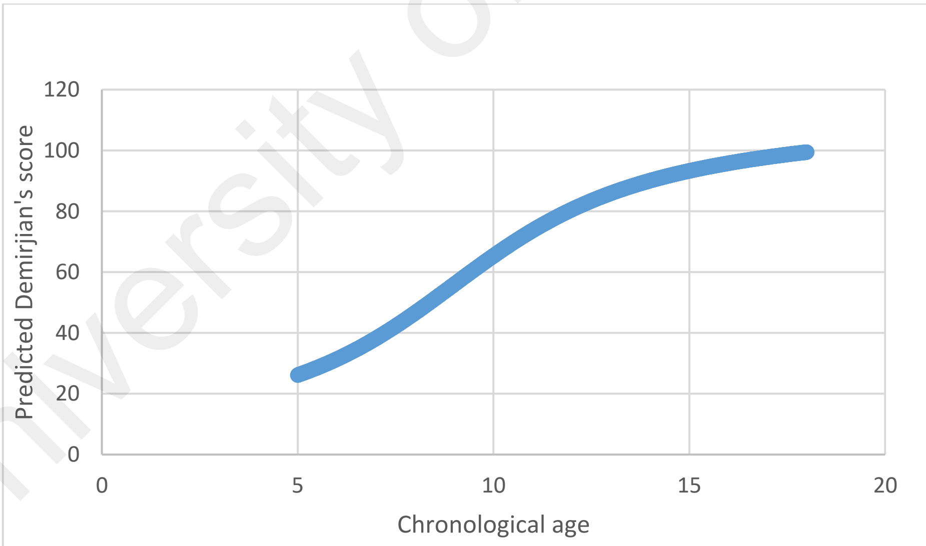

Figure 4.8b: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Malay males following treatment of data with ANN

The relationship between the scores obtained and modified Demirjian's scores in Malay females when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.8c** and **4.8d**, respectively.

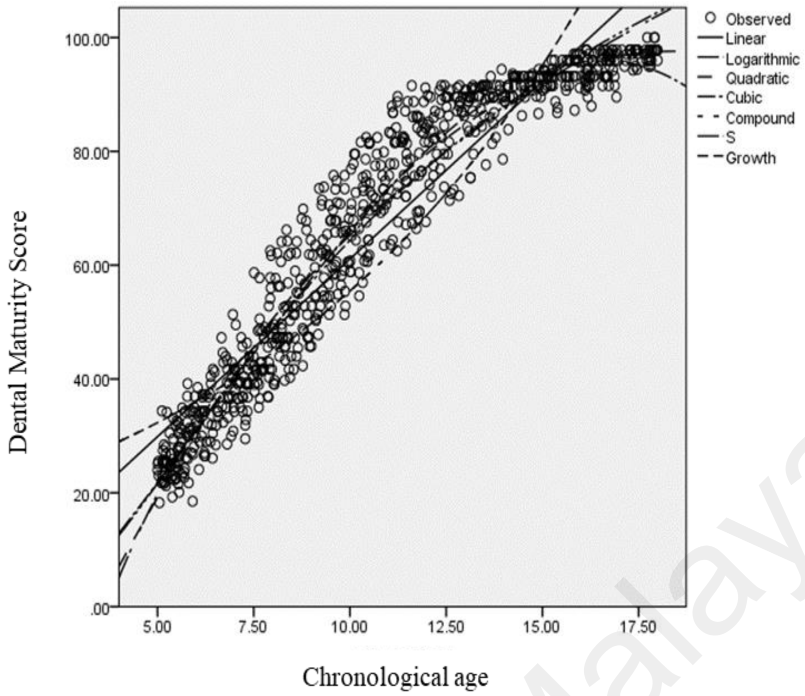

Figure 4.8c: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Malay females by using regression analysis

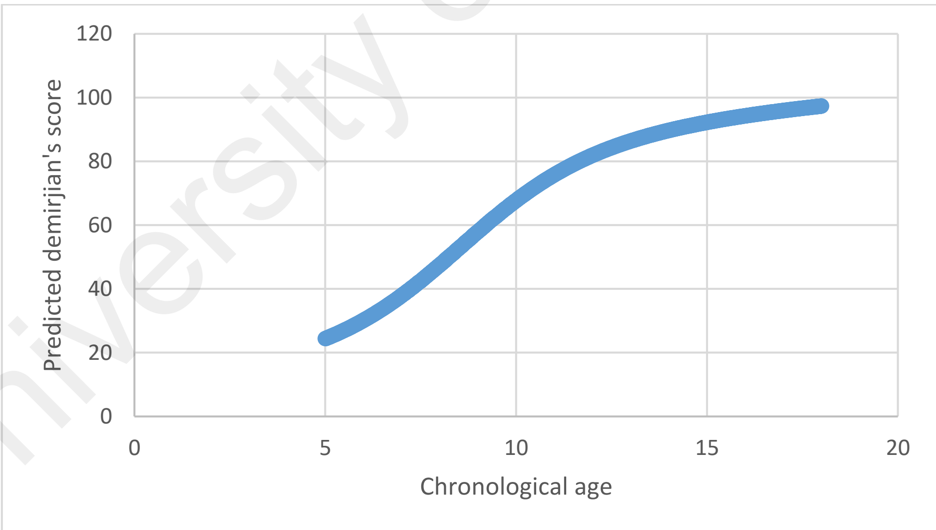

Figure 4.8d: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Malay females following treatment of data with ANN

With both the Malay male and female samples, there was 1 hidden layer consisting of 3 subunits in male and 1 subunit in female that connected the input (CA) to the output (score), after ANN processing (**Figures 4.9a** and **4.9b**, respectively).

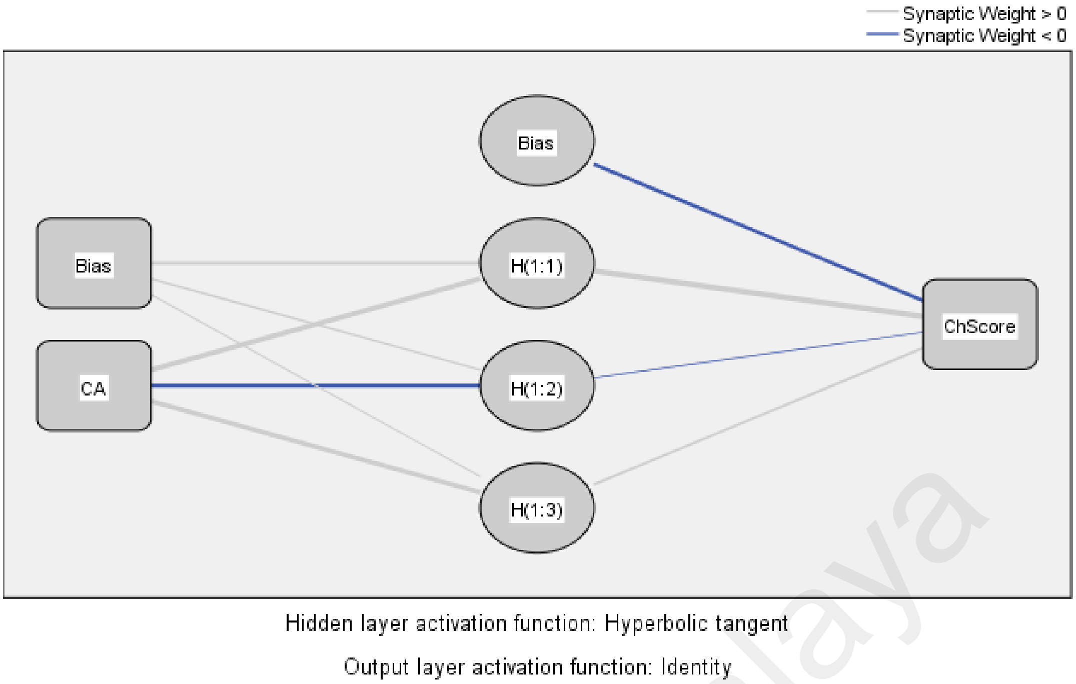

Figure 4.9a: Relationship between chronological age (CA) and modified Demirjian's score (ChScore) in Malay males based on the 8-tooth method. H: hidden layer.

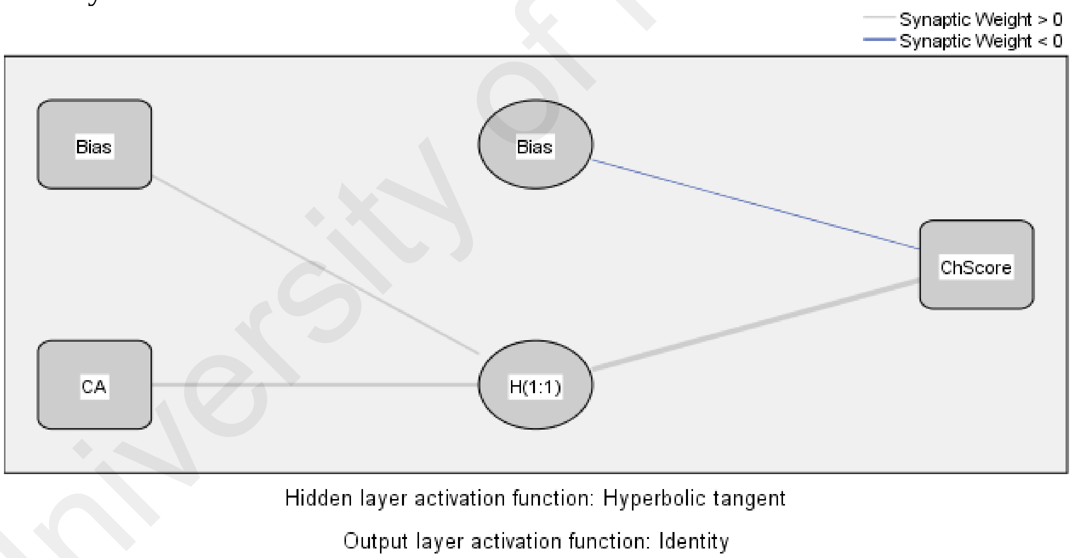

Figure 4.9b: Relationship between chronological age (CA) and modified Demirjian's score (ChScore) in Malay females based on the 8-tooth method. H: hidden layer.

Following treatment of data with ANN, the overall difference between CA and NDA based on the modified method in Malays was not significant when values were pooled together (Table 4.32). The difference was 0.035 years, equivalent to 0.42 months or about 13 days in males, whereas in females, it was 0.048 years, which was equivalent to 0.48 months or about 17 days. These differences contrasted with the pre-ANN values which under-estimated the age of Malay children by more than 2 years (**Table 4.30**).

Table 4.32: Summary for comparison of chronological age and new dental age (determined by using ANN) of modified Demirjian's method in Malays

Gender	N	CA	NDA	NDA-CA	*t*	p
Male	792	10.56 ± 3.76	10.59 ± 3.84	0.035 ± 0.84	1.192	0.234
Female	777	10.78 ± 3.77	10.83 ± 3.87	0.048 ± 0.928	1.443	0.150

Values are mean ± SD. CA: Chronological age. NDA: New dental age. Paired samples t-test, p>0.05.

When the overall data after being subjected to ANN analysis was sliced by age, the difference for each category of age was also not significant for the Malays when the modified Demirjian's method was used (**Tables 4.33a** and **4.33b**).

Table 4.33a: Comparison of chronological age and new dental age based on modified Demirjian's standards as determined by using ANN in Malay males

Age	N	CA		NDA		NDA-CA		95 % CI		*t*	p*
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	92	5.46	0.26	5.55	0.66	0.10	0.60	-0.03	0.22	1.57	0.12
6.0-6.9	66	6.48	0.27	6.57	0.68	0.09	0.60	-0.06	0.24	1.18	0.24
7.0-7.9	88	7.49	0.27	7.46	0.66	-0.03	0.61	-0.16	0.10	-0.48	0.63
8.0-8.9	87	8.46	0.29	8.37	0.71	-0.08	0.67	-0.23	0.06	-1.16	0.25
9.0-9.9	65	9.48	0.31	9.53	0.90	0.05	0.85	-0.16	0.26	0.51	0.61
10.0-10.9	56	10.43	0.28	10.50	0.92	0.07	0.84	-0.15	0.30	0.66	0.51
11.0-11.9	61	11.45	0.28	11.42	0.89	-0.03	0.88	-0.26	0.19	-0.29	0.77
12.0-12.9	58	12.46	0.31	12.45	1.08	0.00	1.02	-0.27	0.26	-0.03	0.98
13.0-13.9	37	13.10	1.25	13.38	1.03	0.28	0.96	-0.04	0.60	1.76	0.09
14.0-14.9	40	14.56	0.29	14.79	1.09	0.23	1.10	-0.12	0.58	1.32	0.19
15.0-15.9	39	15.48	0.29	15.76	1.38	0.28	1.25	-0.12	0.69	1.42	0.16
16.0- 16.9	53	16.44	0.31	16.27	1.25	-0.17	1.21	-0.50	0.17	-1.00	0.32
17.0-17.9	50	17.47	0.30	17.39	0.42	-0.08	0.42	-0.20	0.04	-1.34	0.19

CA: Chronological age. NDA: New dental age. Paired samples t-test. *p>0.05.

Table 4.33b: Comparison of chronological age and new dental age based on modified Demirjian's standards as determined by using ANN in Malay females

Age	N	CA		NDA		NDA-CA		95 % CI		*t*	p*
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	90	5.48	0.28	5.56	0.60	0.08	0.52	-0.03	0.19	1.47	0.15
6.0-6.9	62	6.50	0.31	6.63	0.69	0.13	0.62	-0.03	0.29	1.63	0.11
7.0-7.9	77	7.50	0.30	7.48	0.70	-0.02	0.61	-0.16	0.12	-0.29	0.77
8.0-8.9	70	8.47	0.29	8.42	0.80	-0.05	0.77	-0.23	0.13	-0.56	0.58
9.0-9.9	63	9.50	0.27	9.42	0.78	-0.08	0.76	-0.27	0.11	-0.87	0.39
10.0-10.9	61	10.45	0.29	10.44	0.89	-0.01	0.87	-0.23	0.22	-0.05	0.96
11.0-11.9	64	11.49	0.29	11.70	1.33	0.20	1.34	-0.13	0.54	1.21	0.23
12.0-12.9	51	12.46	0.29	12.71	1.29	0.25	1.25	-0.10	0.60	1.44	0.16
13.0-13.9	51	13.44	0.29	13.62	1.16	0.19	1.16	-0.14	0.51	1.14	0.26
14.0-14.9	40	14.48	0.30	14.64	0.83	0.17	0.82	-0.10	0.43	1.28	0.21
15.0-15.9	45	15.45	0.30	15.54	1.20	0.08	1.14	-0.26	0.43	0.49	0.63
16.0- 16.9	63	16.49	0.28	16.35	1.31	-0.14	1.27	-0.46	0.18	-0.89	0.38
17.0-17.9	40	17.62	0.28	17.52	0.66	-0.10	0.68	-0.31	0.12	-0.90	0.37

CA: Chronological age. NDA: New dental age. Paired samples t-test. *p>0.05.

Thus, based on the data that was subjected to ANN analysis, dental scores that accurately predicted the CA were generated for Malay males and females, respectively (**Tables 4.34** and **4.35**).

Table 4.34: Scores for modified method calculated with ANN and dental age scales for Malay males

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	26.16	9.6	61.68	14.2	90.8
5.1	26.62	9.7	62.61	14.3	91.14
5.2	27.09	9.8	63.53	14.4	91.47
5.3	27.58	9.9	64.45	14.5	91.79
5.4	28.08	10	65.35	14.6	92.11
5.5	28.59	10.1	66.24	14.7	92.42
5.6	29.12	10.2	67.13	14.8	92.72
5.7	29.66	10.3	68	14.9	93.01
5.8	30.22	10.4	68.85	15	93.3
5.9	30.8	10.5	69.7	15.1	93.58
6	31.39	10.6	70.53	15.2	93.85
6.1	32	10.7	71.35	15.3	94.12
6.2	32.62	10.8	72.15	15.4	94.38
6.3	33.27	10.9	72.93	15.5	94.63
6.4	33.92	11	73.71	15.6	94.88
6.5	34.6	11.1	74.46	15.7	95.12
6.6	35.29	11.2	75.21	15.8	95.36
6.7	36	11.3	75.93	15.9	95.59
6.8	36.72	11.4	76.64	16	95.82
6.9	37.47	11.5	77.34	16.1	96.04
7	38.22	11.6	78.01	16.2	96.26
7.1	39	11.7	78.68	16.3	96.47
7.2	39.79	11.8	79.32	16.4	96.68
7.3	40.59	11.9	79.96	16.5	96.88
7.4	41.41	12	80.57	16.6	97.08
7.5	42.25	12.1	81.17	16.7	97.28
7.6	43.1	12.2	81.76	16.8	97.47
7.7	43.96	12.3	82.33	16.9	97.65
7.8	44.83	12.4	82.89	17	97.83
7.9	45.72	12.5	83.43	17.1	98.01
8	46.62	12.6	83.96	17.2	98.19
8.1	47.53	12.7	84.48	17.3	98.36
8.2	48.44	12.8	84.98	17.4	98.53
8.3	49.37	12.9	85.47	17.5	98.69
8.4	50.3	13	85.95	17.6	98.85
8.5	51.24	13.1	86.41	17.7	99.01
8.6	52.19	13.2	86.87	17.8	99.17
8.7	53.14	13.3	87.31	17.9	99.32
8.8	54.09	13.4	87.74	18	99.47
8.9	55.04	13.5	88.15		
9	56	13.6	88.56		
9.1	56.95	13.7	88.96		
9.2	57.9	13.8	89.35		
9.3	58.86	13.9	89.72		
9.4	59.8	14	90.09		
9.5	60.74	14.1	90.45		

Table 4.35: Scores for modified method calculated with ANN and dental age scales for Malay females

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	24.42	9.6	64.05	14.2	90.3
5.1	24.91	9.7	65.01	14.3	90.57
5.2	25.42	9.8	65.95	14.4	90.83
5.3	25.95	9.9	66.88	14.5	91.09
5.4	26.49	10	67.79	14.6	91.34
5.5	27.06	10.1	68.68	14.7	91.58
5.6	27.64	10.2	69.56	14.8	91.82
5.7	28.24	10.3	70.41	14.9	92.05
5.8	28.87	10.4	71.25	15	92.28
5.9	29.51	10.5	72.06	15.1	92.5
6	30.17	10.6	72.86	15.2	92.72
6.1	30.85	10.7	73.63	15.3	92.94
6.2	31.56	10.8	74.39	15.4	93.14
6.3	32.28	10.9	75.12	15.5	93.35
6.4	33.03	11	75.84	15.6	93.55
6.5	33.8	11.1	76.53	15.7	93.74
6.6	34.59	11.2	77.21	15.8	93.93
6.7	35.4	11.3	77.86	15.9	94.12
6.8	36.23	11.4	78.5	16	94.3
6.9	37.08	11.5	79.12	16.1	94.49
7	37.95	11.6	79.72	16.2	94.66
7.1	38.84	11.7	80.3	16.3	94.84
7.2	39.75	11.8	80.86	16.4	95.01
7.3	40.67	11.9	81.41	16.5	95.17
7.4	41.61	12	81.94	16.6	95.34
7.5	42.57	12.1	82.45	16.7	95.5
7.6	43.55	12.2	82.95	16.8	95.66
7.7	44.54	12.3	83.43	16.9	95.81
7.8	45.54	12.4	83.9	17	95.97
7.9	46.55	12.5	84.35	17.1	96.12
8	47.57	12.6	84.79	17.2	96.27
8.1	48.6	12.7	85.21	17.3	96.41
8.2	49.64	12.8	85.63	17.4	96.55
8.3	50.68	12.9	86.03	17.5	96.69
8.4	51.73	13	86.42	17.6	96.83
8.5	52.78	13.1	86.79	17.7	96.97
8.6	53.83	13.2	87.16	17.8	97.1
8.7	54.88	13.3	87.51	17.9	97.24
8.8	55.93	13.4	87.86	18	97.37
8.9	56.98	13.5	88.2		
9	58.01	13.6	88.52		
9.1	59.04	13.7	88.84		
9.2	60.07	13.8	89.15		
9.3	61.08	13.9	89.45		
9.4	62.08	14	89.74		
9.5	63.07	14.1	90.02		

4.2.2.2 Dental age estimation in Chinese subjects using modified Chaillet & Demirjian's method 2004

A total of 1228 Chinese samples were analysed (**Table 4.36**).

Table 4.36: Distribution of Chinese subjects by age and sex

Chronological age (years)	Male (%)	Female (%)	Total (%)
5.0-5.9	48 (7.81)	38 (6.20)	86 (7.00)
6.0-6.9	52 (8.50)	54 (8.80)	106 (8.63)
7.0-7.9	64 (10.42)	32 (5.20)	96 (7.82)
8.0-8.9	57 (9.28)	54 (8.80)	111 (9.04)
9.0-9.9	29 (4.72)	50 (8.10)	79 (6.43)
10.0-10.9	56 (9.12)	40 (6.50)	96 (7.82)
11.0-11.9	36 (5.86)	50 (8.10)	86 (7.00)
12.0-12.9	58 (9.44)	39 (6.40)	97 (7.90)
13.0-13.9	32 (5.21)	42 (6.80)	74 (6.03)
14.0-14.9	42 (6.84)	39 (6.40)	81 (6.60)
15.0-15.9	50 (8.14)	69 (11.20)	119 (9.69)
16.00-16.9	31 (5.05)	45 (7.30)	76 (6.19)
17.0-17.9	59 (9.61)	62 (10.10)	121 (9.85)
Total	614 (100.00)	614 (100.00)	1228 (100.00)

Comparison between CA and DA in Chinese males showed significant differences in all age groups (**Table 4.37a**).

Table 4.37a: Comparison of chronological age and dental age as determined by using modified Demirjian's standards in Chinese males

Age	N	CA		DA		DA-CA		95 % CI		*t*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	48	5.52	0.32	3.18	0.77	-2.34	0.71	-2.55	-2.13	-22.86	0.00*
6.0-6.9	52	6.51	0.27	4.43	0.69	-2.08	0.68	-2.27	-1.89	-22.01	0.00*
7.0-7.9	64	7.52	0.29	5.44	0.76	-2.08	0.68	-2.25	-1.91	-24.45	0.00*
8.0-8.9	57	8.52	0.28	6.30	0.77	-2.22	0.68	-2.40	-2.04	-24.70	0.00*
9.0-9.9	29	9.41	0.31	7.59	0.82	-1.81	0.72	-2.09	-1.54	-13.49	0.00*
10.0-10.9	56	10.53	0.30	8.94	0.78	-1.60	0.71	-1.79	-1.40	-16.75	0.00*
11.0-11.9	36	11.49	0.28	9.72	0.89	-1.76	0.80	-2.03	-1.49	-13.22	0.00*
12.0-12.9	58	12.45	0.31	10.86	1.03	-1.60	1.02	-1.86	-1.33	-11.96	0.00*
13.0-13.9	32	13.48	0.31	11.92	1.04	-1.55	0.95	-1.90	-1.21	-9.29	0.00*
14.0-14.9	42	14.49	0.27	12.66	0.81	-1.83	0.90	-2.11	-1.55	-13.13	0.00*
15.0-15.9	50	15.49	0.28	13.77	1.11	-1.72	1.10	-2.03	-1.41	-11.07	0.00*
16.0- 16.9	31	16.56	0.29	14.79	1.36	-1.77	1.21	-2.21	-1.32	-8.13	0.00*
17.0-17.9	59	17.47	0.29	15.23	1.36	-2.24	1.36	-2.59	-1.89	-12.69	0.00*

CA: Chronological age. DA: Dental age. Paired samples t-test. * Statistically significant at the 0.05 level.

Similarly, comparison between CA and DA in Chinese females showed significant differences in all age groups (**Table 4.37b**).

Table 4.37b: Comparison of chronological age and dental age as determined by using modified Demirjian's standards in Chinese females

Age	N	CA		DA		DA-CA		95 % CI		*t*	p
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	38	5.48	0.32	2.79	0.88	-2.69	0.76	-2.94	-2.44	-21.77	0.00*
6.0-6.9	54	6.53	0.26	4.34	0.63	-2.18	0.58	-2.34	-2.03	-27.87	0.00*
7.0-7.9	32	7.42	0.30	5.14	0.74	-2.28	0.68	-2.52	-2.03	-18.98	0.00*
8.0-8.9	54	8.51	0.30	6.23	0.76	-2.29	0.66	-2.47	-2.11	-25.31	0.00*
9.0-9.9	50	9.55	0.29	7.10	0.83	-2.45	0.70	-2.65	-2.26	-24.93	0.00*
10.0-10.9	40	10.51	0.28	8.31	0.80	-2.20	0.76	-2.44	-1.96	-18.40	0.00*
11.0-11.9	50	11.48	0.28	9.29	0.96	-2.19	0.85	-2.44	-1.95	-18.19	0.00*
12.0-12.9	39	12.49	0.30	10.19	1.04	-2.30	1.07	-2.65	-1.96	-13.51	0.00*
13.0-13.9	42	13.54	0.31	10.97	0.88	-2.56	0.86	-2.83	-2.30	-19.26	0.00*
14.0-14.9	39	14.46	0.29	11.53	0.87	-2.94	0.88	-3.22	-2.65	-20.91	0.00*
15.0-15.9	69	15.47	0.29	12.18	0.96	-3.29	0.92	-3.51	-3.07	-29.61	0.00*
16.0- 16.9	45	16.49	0.32	12.83	0.80	-3.65	0.81	-3.90	-3.41	-30.39	0.00*
17.0-17.9	62	17.53	0.26	13.43	1.16	-4.10	1.18	-4.40	-3.80	-27.38	0.00*

CA: Chronological age. DA: Dental age. Paired samples t-test. * Statistically significant at the 0.05 level.

Overall, the difference between CA and DA in Chinese when the modified Demirjian's method was used was significant when values were pooled together (**Table 4.38**). The difference represented under-estimation by 1.92 years in males and 2.76 years in females.

Table 4.38: Summary for comparison of chronological age and dental age (determined by using the modified Demirjian's standards) in Chinese subjects

Gender	N	CA	DA	DA-CA	*t*	p
Male	614	11.28 ± 3.83	9.36 ± 4.03	-1.92 ± 0.94	-50.63	0.0001*
Female	614	11.80 ± 3.82	9.04 ± 3.44	-2.76 ± 1.05	-64.90	0.0001*

CA: Chronological age. DA: Dental age. Paired samples t-test. *Statistically significant at the 0.05 level.

The correlation between CA and modified Demirjian's scores was very high (**Table 4.39**). Although the correlation was high, the difference between CA and scores based on the modified method was significant.

Table 4.39: Correlation between chronological age, modified Demirjian's scores and predicted values for modified Demirjian's scores in the Chinese

		Chronological age	
		Male	**Female**
Modified Demirjian's score	r	0.982**	0.977**
	p	0.0001	0.0001
Predicted value for Demirjian's modified score	R/r	0.982**	0.977**
	P	0.0001	0.0001

Correlation analysis, r; *Significant at the 0.01 level (2-tailed).

The relationship between the scores obtained and modified Demirjian's scores in Chinese males when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.10a** and **4.10b**, respectively.

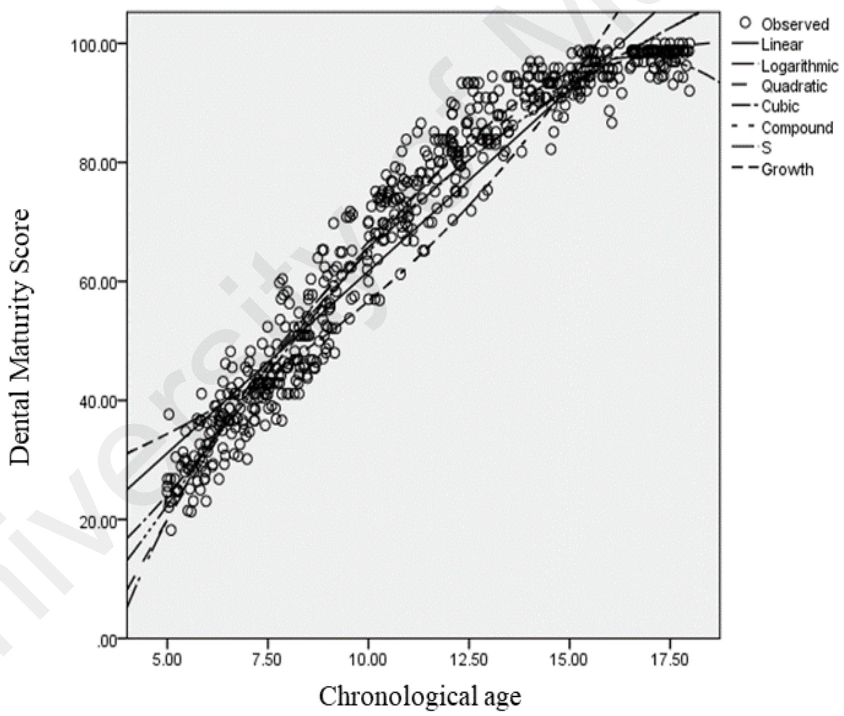

Figure 4.10a: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Chinese males by using regression analysis

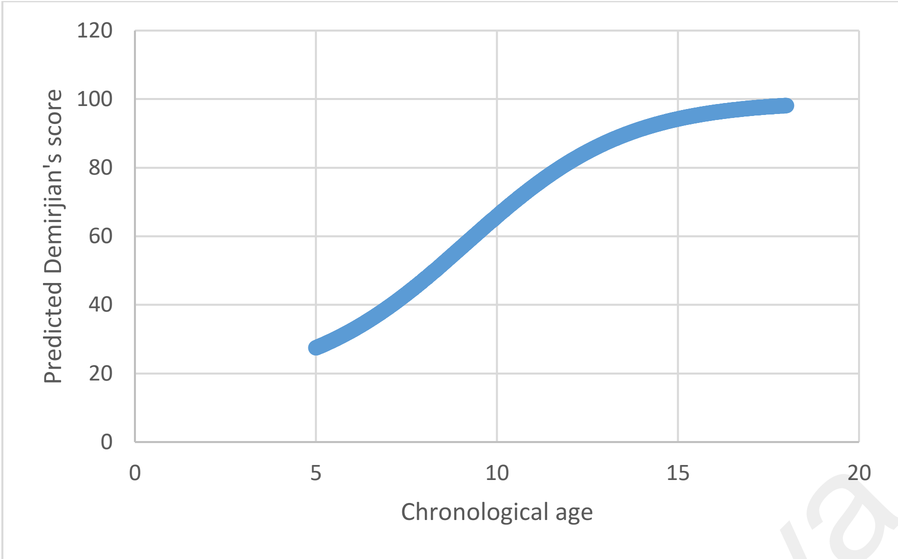

Figure 4.10b: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Chinese males following treatment of data with ANN

The relationship between the scores obtained and modified Demirjian's scores in Chinese females when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.10c** and **4.10d**, respectively.

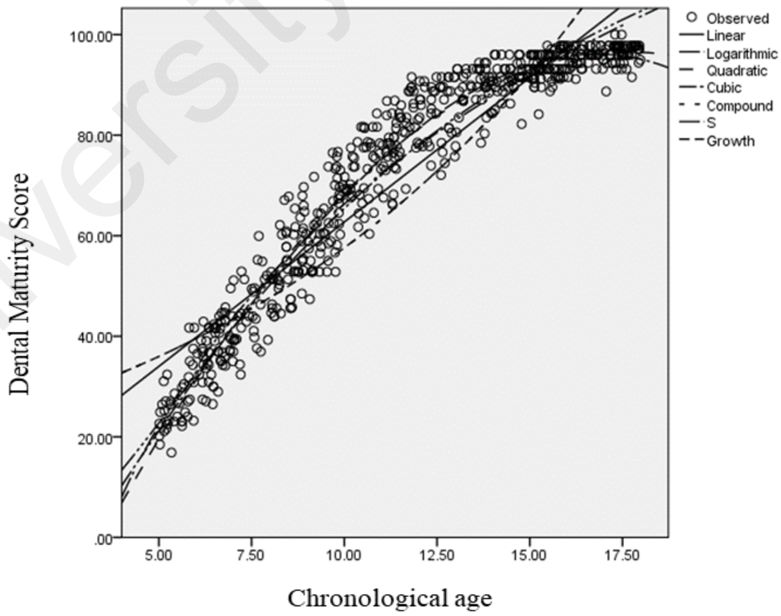

Figure 4.10c: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Chinese females by using regression analysis

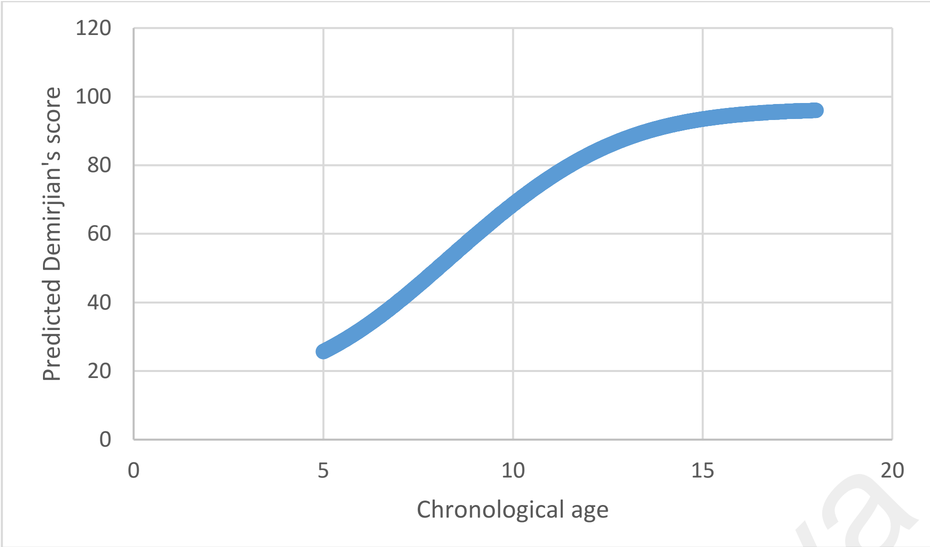

Figure 4.10d: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Chinese females following treatment of data with ANN

With both the Chinese male and female samples, there is 1 hidden layer consisting of 2 subunits in male and 1 subunit in female that connect the input (CA) to the output (score), after ANN processing (**Figures 4.11a** and **4.11b**).

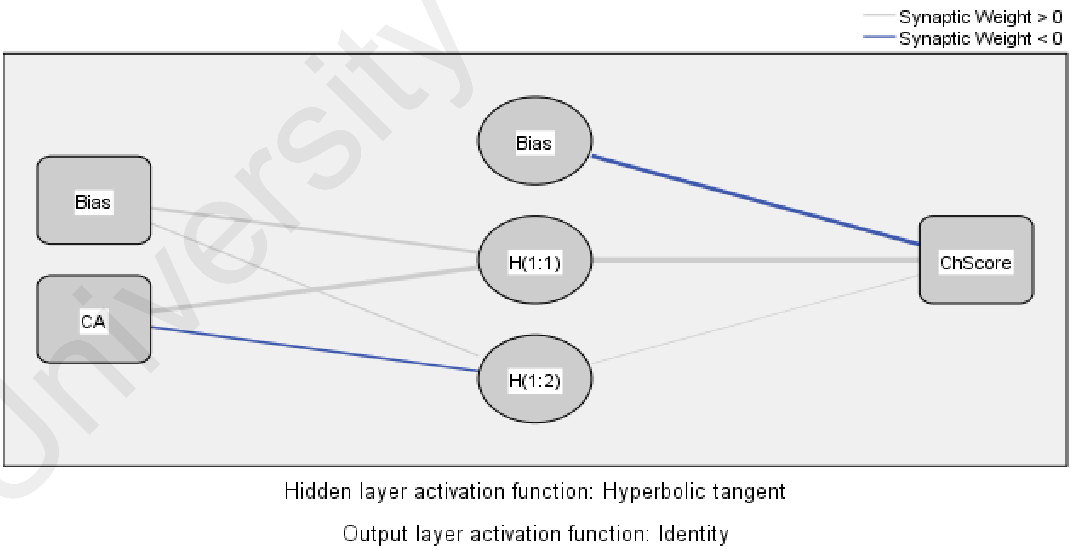

Figure 4.11a: Relationship between chronological age (CA) and modified Demirjian's score (ChScore) in Chinese males based on the 8-tooth method. H: hidden layer.

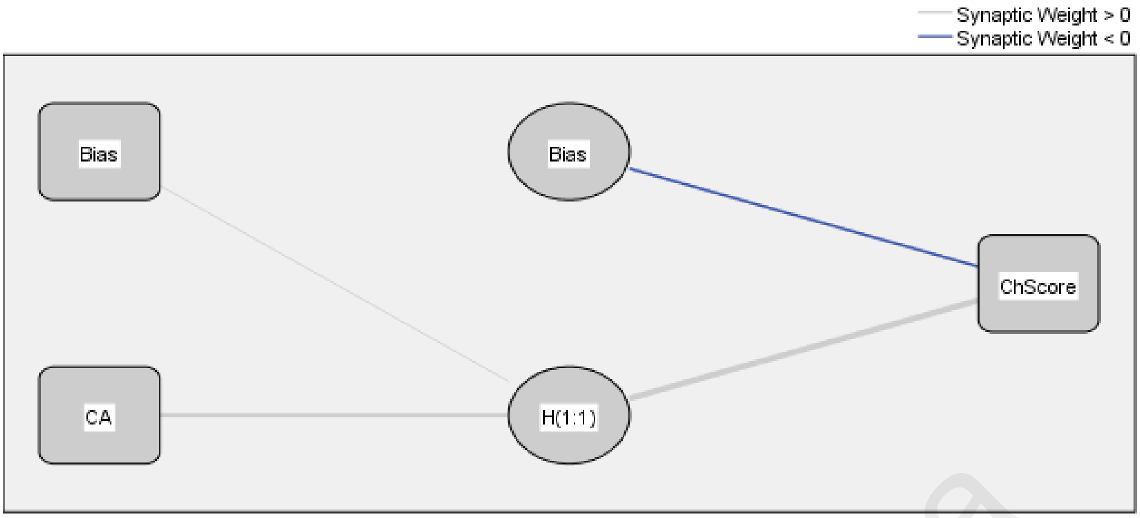

Figure 4.11b: Relationship between chronological age (CA) and modified Demirjian's score (ChScore) in Chinese females based on the 8-tooth method. H: hidden layer**.**

After treatment of data with ANN, the overall difference between CA and NDA in the Chinese using paired-samples t-test was not significant when values were pooled together (**Table 4.40**). The difference was 0.05 years, equivalent to 0.6 months or 18 days in males, whereas in females it was 0.06 years, which was equivalent to 0.7 months or about 22 days. This contrasted with the pre-ANN values whereby the Chinese children were significantly under-estimated in terms of their age by more than 1.9 years (**Table 4.38**).

Table 4.40: Summary for comparison of chronological age and new dental age (determined by using ANN) of modified Demirjian's method in Chinese subjects

Gender	N	CA	NDA	NDA-CA	*t*	p
Male	614	11.28 ± 3.83	11.32 ± 3.96	0.048 ± 0.92	1.282	0.20
Female	614	11.80 ± 3.82	11.86 ± 4.01	0.059 ± 1.11	1.327	0.185

Values are mean ± SD. CA: Chronological age. NDA: New dental age. Paired samples t-test, p>0.05.

When the overall data after being subjected to ANN analysis was sliced by age, the difference for each category of age was not significant for the Chinese subjects based on the modified Demirjian's method (**Tables 4.41a** and **4.41b**).

Table 4.41a: Comparison of chronological age and new dental age based on modified Demirjian's standards as determined by using ANN in Chinese males

Age	N	CA		NDA		NDA-CA		95 % CI		*t*	p*
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	48	5.52	0.32	5.46	0.62	-0.06	0.59	-0.23	0.11	-0.68	0.50
6.0-6.9	52	6.51	0.27	6.60	0.70	0.10	0.68	-0.10	0.29	1.01	0.32
7.0-7.9	64	7.52	0.29	7.59	0.68	0.07	0.61	-0.08	0.22	0.90	0.37
8.0-8.9	57	8.52	0.28	8.37	0.68	-0.14	0.59	-0.30	0.01	-1.83	0.07
9.0-9.9	29	9.41	0.31	9.50	0.74	0.09	0.64	-0.15	0.33	0.75	0.46
10.0-10.9	56	10.53	0.30	10.68	0.68	0.14	0.61	-0.02	0.31	1.75	0.09
11.0-11.9	36	11.49	0.28	11.39	0.80	-0.10	0.72	-0.34	0.15	-0.79	0.44
12.0-12.9	58	12.45	0.31	12.51	1.08	0.05	1.06	-0.23	0.33	0.37	0.71
13.0-13.9	32	13.48	0.31	13.62	1.14	0.15	1.04	-0.23	0.52	0.80	0.43
14.0-14.9	42	14.49	0.27	14.46	0.97	-0.03	1.05	-0.36	0.30	-0.18	0.86
15.0-15.9	50	15.49	0.28	15.84	1.41	0.35	1.39	-0.05	0.74	1.76	0.08
16.0- 16.9	31	16.56	0.29	16.99	1.46	0.43	1.27	-0.04	0.89	1.88	0.07
17.0-17.9	59	17.47	0.29	17.24	1.18	-0.22	1.20	-0.54	0.09	-1.44	0.16

CA: Chronological age. NDA: New dental age. Paired samples t-test, *p>0.05.

Table 4.41b: Comparison of chronological age and new dental age based on modified Demirjian's standards as determined by using ANN in Chinese females

Age	N	CA		NDA		DA-CA		95 % CI		*t*	p*
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	38	5.48	0.32	5.41	0.62	-0.06	0.52	-0.23	0.11	-0.77	0.45
6.0-6.9	54	6.53	0.26	6.64	0.64	0.11	0.58	-0.05	0.27	1.43	0.16
7.0-7.9	32	7.42	0.30	7.43	0.73	0.01	0.67	-0.24	0.25	0.05	0.97
8.0-8.9	54	8.51	0.30	8.52	0.76	0.01	0.65	-0.17	0.19	0.09	0.93
9.0-9.9	50	9.55	0.29	9.40	0.83	-0.15	0.70	-0.35	0.05	-1.54	0.13
10.0-10.9	40	10.51	0.28	10.62	0.79	0.11	0.76	-0.14	0.35	0.89	0.38
11.0-11.9	50	11.48	0.28	11.62	1.02	0.14	0.91	-0.12	0.40	1.10	0.28
12.0-12.9	39	12.49	0.30	12.55	1.16	0.06	1.18	-0.32	0.45	0.34	0.73
13.0-13.9	42	13.54	0.31	13.61	1.19	0.07	1.17	-0.29	0.44	0.40	0.69
14.0-14.9	39	14.46	0.29	14.55	1.67	0.08	1.67	-0.46	0.63	0.31	0.76
15.0-15.9	69	15.47	0.29	15.68	1.79	0.21	1.77	-0.21	0.64	1.00	0.32
16.0- 16.9	45	16.49	0.32	16.82	1.40	0.33	1.35	-0.08	0.74	1.63	0.11
17.0-17.9	62	17.53	0.26	17.37	1.22	-0.15	1.20	-0.46	0.15	-1.01	0.32

CA: Chronological age. NDA: New dental age. Paired samples t-test. *p>0.05.

Thus, based on the data that was subjected to ANN analysis, dental scores that accurately predicted the CA were generated for Chinese males and females, respectively (**Tables 4.42** and **4.43**).

Table 4.42: Scores for modified method calculated with ANN and dental age scales for Chinese males

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	27.51	9.6	62.23	14.2	92.08
5.1	27.95	9.7	63.15	14.3	92.4
5.2	28.41	9.8	64.07	14.4	92.7
5.3	28.88	9.9	64.99	14.5	92.99
5.4	29.37	10	65.9	14.6	93.26
5.5	29.88	10.1	66.8	14.7	93.53
5.6	30.39	10.2	67.7	14.8	93.79
5.7	30.93	10.3	68.58	14.9	94.04
5.8	31.48	10.4	69.46	15	94.27
5.9	32.04	10.5	70.32	15.1	94.5
6	32.63	10.6	71.18	15.2	94.72
6.1	33.22	10.7	72.02	15.3	94.93
6.2	33.84	10.8	72.85	15.4	95.13
6.3	34.47	10.9	73.67	15.5	95.33
6.4	35.11	11	74.47	15.6	95.51
6.5	35.77	11.1	75.26	15.7	95.69
6.6	36.45	11.2	76.04	15.8	95.86
6.7	37.15	11.3	76.8	15.9	96.02
6.8	37.86	11.4	77.54	16	96.18
6.9	38.58	11.5	78.28	16.1	96.33
7	39.32	11.6	78.99	16.2	96.47
7.1	40.08	11.7	79.69	16.3	96.6
7.2	40.85	11.8	80.37	16.4	96.74
7.3	41.63	11.9	81.04	16.5	96.86
7.4	42.43	12	81.69	16.6	96.98
7.5	43.24	12.1	82.33	16.7	97.09
7.6	44.06	12.2	82.95	16.8	97.2
7.7	44.9	12.3	83.55	16.9	97.31
7.8	45.75	12.4	84.14	17	97.4
7.9	46.61	12.5	84.71	17.1	97.5
8	47.48	12.6	85.26	17.2	97.59
8.1	48.36	12.7	85.8	17.3	97.68
8.2	49.25	12.8	86.32	17.4	97.76
8.3	50.15	12.9	86.83	17.5	97.84
8.4	51.06	13	87.32	17.6	97.91
8.5	51.97	13.1	87.79	17.7	97.98
8.6	52.89	13.2	88.25	17.8	98.05
8.7	53.82	13.3	88.7	17.9	98.11
8.8	54.74	13.4	89.13	18	98.17
8.9	55.68	13.5	89.54		
9	56.61	13.6	89.95		
9.1	57.55	13.7	90.34		
9.2	58.49	13.8	90.71		
9.3	59.42	13.9	91.07		
9.4	60.36	14	91.42		
9.5	61.29	14.1	91.76		

Table 4.43: Scores for modified method calculated with ANN and dental age scales for Chinese females

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	25.7	9.6	65.06	14.2	91.83
5.1	26.26	9.7	65.96	14.3	92.08
5.2	26.84	9.8	66.85	14.4	92.31
5.3	27.44	9.9	67.73	14.5	92.53
5.4	28.06	10	68.6	14.6	92.74
5.5	28.7	10.1	69.46	14.7	92.95
5.6	29.36	10.2	70.31	14.8	93.14
5.7	30.04	10.3	71.14	14.9	93.32
5.8	30.73	10.4	71.96	15	93.5
5.9	31.45	10.5	72.77	15.1	93.66
6	32.18	10.6	73.56	15.2	93.82
6.1	32.93	10.7	74.34	15.3	93.97
6.2	33.7	10.8	75.11	15.4	94.12
6.3	34.48	10.9	75.86	15.5	94.25
6.4	35.28	11	76.59	15.6	94.38
6.5	36.1	11.1	77.31	15.7	94.5
6.6	36.93	11.2	78.02	15.8	94.62
6.7	37.78	11.3	78.71	15.9	94.73
6.8	38.65	11.4	79.38	16	94.83
6.9	39.52	11.5	80.04	16.1	94.93
7	40.41	11.6	80.68	16.2	95.03
7.1	41.31	11.7	81.31	16.3	95.11
7.2	42.22	11.8	81.91	16.4	95.2
7.3	43.14	11.9	82.51	16.5	95.28
7.4	44.08	12	83.08	16.6	95.35
7.5	45.01	12.1	83.64	16.7	95.42
7.6	45.96	12.2	84.18	16.8	95.49
7.7	46.91	12.3	84.71	16.9	95.55
7.8	47.87	12.4	85.22	17	95.61
7.9	48.84	12.5	85.71	17.1	95.67
8	49.8	12.6	86.19	17.2	95.72
8.1	50.77	12.7	86.65	17.3	95.77
8.2	51.74	12.8	87.1	17.4	95.81
8.3	52.72	12.9	87.53	17.5	95.86
8.4	53.69	13	87.94	17.6	95.9
8.5	54.66	13.1	88.34	17.7	95.94
8.6	55.63	13.2	88.73	17.8	95.97
8.7	56.6	13.3	89.1	17.9	96
8.8	57.56	13.4	89.46	18	96.04
8.9	58.52	13.5	89.8		
9	59.47	13.6	90.13		
9.1	60.42	13.7	90.44		
9.2	61.36	13.8	90.75		
9.3	62.3	13.9	91.04		
9.4	63.23	14	91.31		
9.5	64.15	14.1	91.58		

4.2.2.3 Dental age estimation in Indians using modified Chaillet & Demirjian's method 2004

A total of 1015 Indian samples were analysed (**Table 4.44**).

Table 4.44: Distribution of Indian subjects by age and sex

Chronological age (years)	Male (%)	Female (%)	Total (%)
5.0-5.9	26 (5.26)	28 (5.37)	54 (5.32)
6.0-6.9	42 (8.50)	34 (6.53)	76 (7.49)
7.0-7.9	40 (8.10)	27 (5.18)	67 (6.60)
8.0-8.9	34 (6.88)	48 (9.21)	82 (8.08)
9.0-9.9	38 (7.69)	35 (6.72)	73 (7.19)
10.0-10.9	44 (8.91)	44 (8.45)	88 (8.67)
11.0-11.9	46 (9.31)	46 (8.83)	92 (9.06)
12.0-12.9	47 (9.51)	45 (8.64)	92 (9.06)
13.0-13.9	39 (7.89)	48 (9.21)	87 (8.57)
14.0-14.9	32 (6.48)	45 (8.64)	77 (7.59)
15.0-15.9	43 (8.70)	31 (5.95)	74 (7.29)
16.00-16.9	44 (8.91)	46 (8.83)	90 (8.87)
17.0-17.9	19 (3.85)	44 (8.45)	63 (6.21)
Total	494 (100.00)	521 (100.00)	1015 (100.00)

Comparison between CA and DA in Indian males showed significant differences in all age groups when the modified Demirjian's method was used (**Table 4.45a**).

Table 4.45a: Comparison of chronological age and dental age as determined by using modified Demirjian's standards in Indian males

Age	N	CA		DA		DA-CA		95 % CI		*t/z*	p*
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	26	5.52	0.25	3.24	0.69	-2.28	0.73	-2.58	-1.99	-15.87	0.00
6.0-6.9	42	6.56	0.30	4.27	0.93	-2.29	0.78	-2.54	-2.05	-18.93	0.00
7.0-7.9	40	7.49	0.32	5.64	1.01	-1.85	0.82	-2.11	-1.59	-14.35	0.00
8.0-8.9	34	8.51	0.27	6.73	0.95	-1.78	0.84	-2.07	-1.49	-12.43	0.00
9.0-9.9	38	9.54	0.30	7.97	0.91	-1.57	0.84	-1.85	-1.29	-11.47	0.00
10.0-10.9	44	10.48	0.29	9.01	0.97	-1.47	0.91	-1.75	-1.19	-10.72	0.00
11.0-11.9	46	11.51	0.27	9.74	1.02	-1.77	0.98	-2.06	-1.48	-12.29	0.00
12.0-12.9	47	12.44	0.31	10.93	1.21	-1.51	1.21	-1.87	-1.16	-8.58	0.00
13.0-13.9	39	13.54	0.36	11.79	1.20	-1.75	1.02	-2.08	-1.42	-10.68	0.00
14.0-14.9	32	14.54	0.31	12.88	0.59	-1.66	0.60	-1.87	-1.44	-15.73	0.00
15.0-15.9	43	15.54	0.28	14.03	1.12	-1.51	1.01	-1.82	-1.20	-9.83	0.00
16.0- 16.9	44	16.56	0.29	14.93	1.23	-1.57	1.21	-1.93	-1.20	-8.57	0.00
17.0-17.9[a]	19	17.47	0.29	16.93	1.15	-0.52	0.95	-0.98	-0.06	-1.61	0.11

CA: Chronological age. DA: Dental age. Paired samples t-test. *Statistically significant at the 0.05 level.
a: Based on Wilcoxon test due to small sample size.

Similarly, comparison between CA and DA in Indian females showed significant differences in all age groups (**Table 4.45b**).

Table 4.45b: Comparison of chronological age and dental age as determined by using modified Demirjian's standards in Indian females

Age	N	CA		DA		DA-CA		95 % CI		*t*	p*
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	28	5.53	0.29	3.08	0.84	-2.45	0.73	-2.73	-2.16	-17.61	0.00
6.0-6.9	34	6.52	0.30	4.14	0.59	-2.38	0.60	-2.59	-2.17	-23.21	0.00
7.0-7.9	27	7.50	0.28	5.14	0.68	-2.36	0.65	-2.61	-2.10	-18.96	0.00
8.0-8.9	48	8.48	0.32	6.26	0.89	-2.22	0.79	-2.45	-1.99	-19.40	0.00
9.0-9.9	35	9.46	0.31	7.42	0.85	-2.04	0.79	-2.31	-1.77	-15.30	0.00
10.0-10.9	44	10.49	0.27	8.40	0.85	-2.09	0.82	-2.34	-1.84	-16.86	0.00
11.0-11.9	46	11.52	0.26	9.50	0.99	-2.02	0.97	-2.31	-1.73	-14.07	0.00
12.0-12.9	45	12.43	0.27	10.17	1.06	-2.26	1.05	-2.58	-1.94	-14.44	0.00
13.0-13.9	48	13.55	0.26	11.07	0.75	-2.49	0.77	-2.71	-2.26	-22.36	0.00
14.0-14.9	45	14.46	0.25	11.79	0.85	-2.67	0.86	-2.92	-2.41	-20.90	0.00
15.0-15.9	31	15.48	0.28	12.41	0.85	-3.07	0.75	-3.35	-2.80	-22.87	0.00
16.0- 16.9	46	16.51	0.30	13.11	0.86	-3.40	0.86	-3.65	-3.14	-26.83	0.00
17.0-17.9	44	17.48	0.33	13.75	1.06	-3.73	1.06	-4.05	-3.41	-23.44	0.00

CA: Chronological age. DA: Dental age. Paired samples t-test. *Statistically significant at the 0.05 level.

Overall, the difference between CA and DA in Indians when the modified Demirjian's method was used was significant when values were pooled together (**Table 4.46**). The difference represented under-estimation by 1.68 years in males and 2.56 years in females.

Table 4.46: Summary for comparison of chronological age and dental age (determined by using the modified Demirjian's standards) in Indians

Gender	N	CA	DA	DA-CA	*t*	p
Male	494	11.47 ± 3.52	9.78 ±3.90	-1.68 ± 1.00	-37.520	0.0001*
Female	521	11.86 ± 3.60	9.30 ± 3.33	-2.56 ± 1.00	-58.812	0.0001*

CA: Chronological age. DA: Dental age. Paired samples t-test. *Statistically significant at the 0.05 level.

Similar to those values for the Malays and Chinese subjects, the correlation between CA and Demirjian's scores was very high (**Table 4.47**). Despite showing highly significant correlation (p<0.001), the difference between CA and scores was significant.

Table 4.47: Correlation between chronological age, modified Demirjian's scores and predicted values for modified Demirjian's scores in Indians

		Chronological age	
		Male	**Female**
Modified Demirjian's score	r	0.976^{**}	0.975^{**}
	p	0.0001	0.0001
Predicted value for Demirjian's modified score	R/r	0.976^{**}	0.975^{**}
	P	0.0001	0.0001

Correlation analysis, r; *Significant at the 0.01 level (2-tailed).

The relationship between the scores obtained and modified Demirjian's scores in Indian males when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.12a** and **4.12b**, respectively.

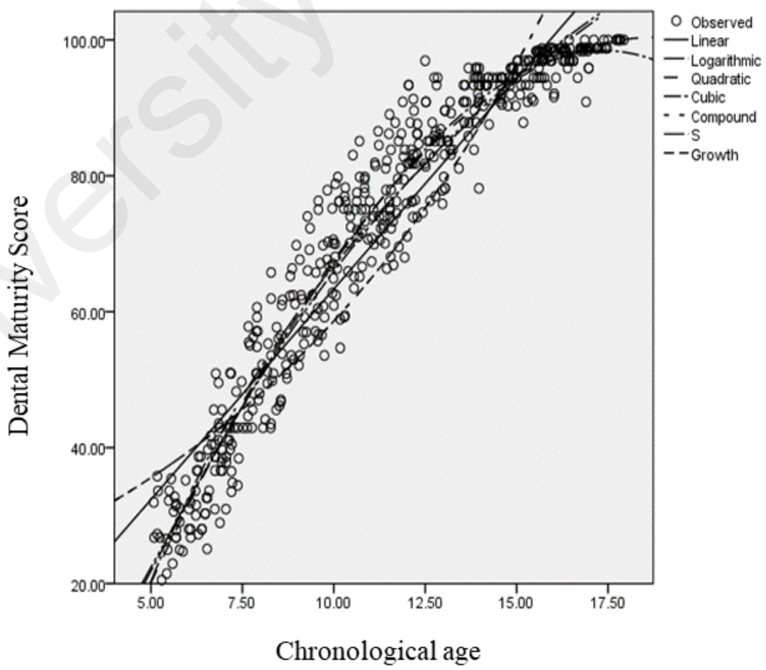

Figure 4.12a: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Indian males by using regression analysis

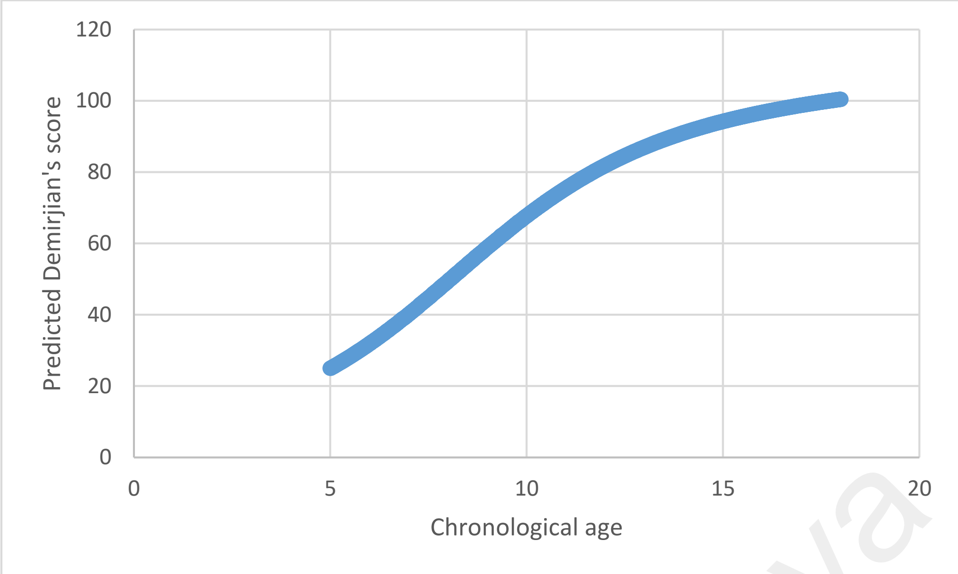

Figure 4.12b: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Indian males following treatment of data with ANN

The relationship between the scores obtained and modified Demirjian's scores in Indian females when the data was analysed using regression analysis and analysed after ANN treatment are shown in **Figures 4.12c** and **4.12db**, respectively.

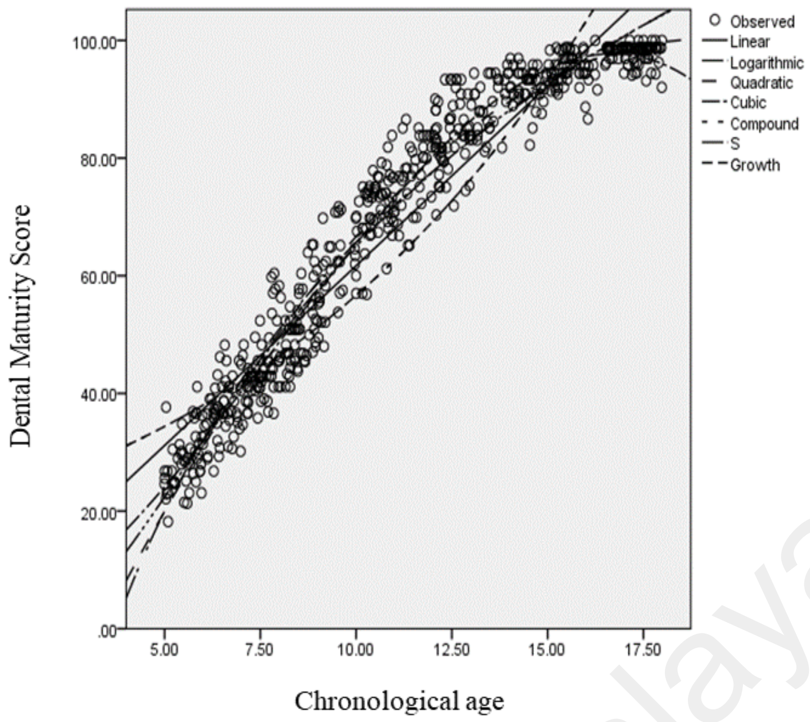

Figure 4.12c: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Indian females by using regression analysis

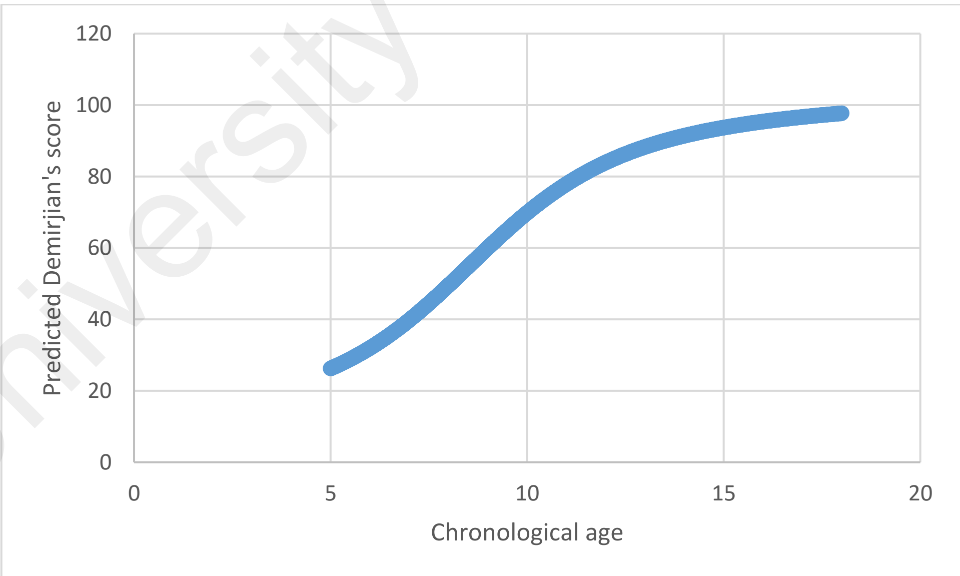

Figure 4.12d: Distribution of score sums based on modified Demirjian's scores plotted against median values of obtained scores for Indian females following treatment of data with ANN

With both the Indian male and female samples, there was 1 hidden layer consisting of 3 subunits in male and 2 subunits in female that connected the input (CA) to the output (score), after ANN processing (Figures 4.13a and b). This was similar to the relationship found in the Malay and Chinese subjects.

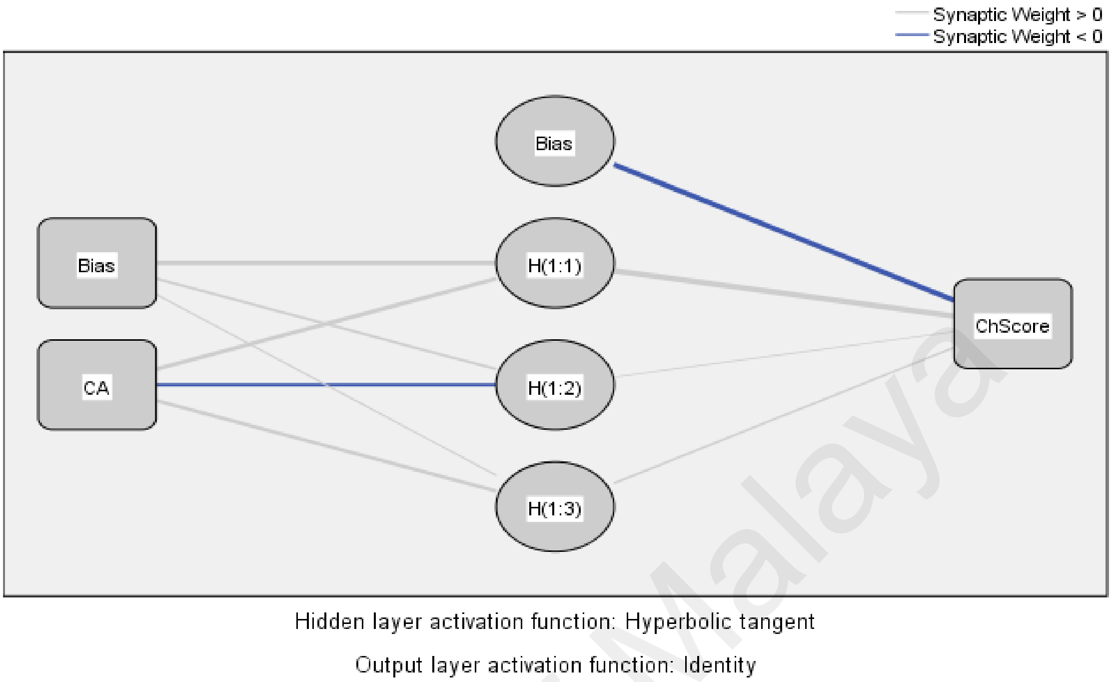

Figure 4.13a: Relationship between chronological age (CA) and modified Demirjian's score (ChScore) in Indian males based on the 8-tooth method. H: hidden layer.

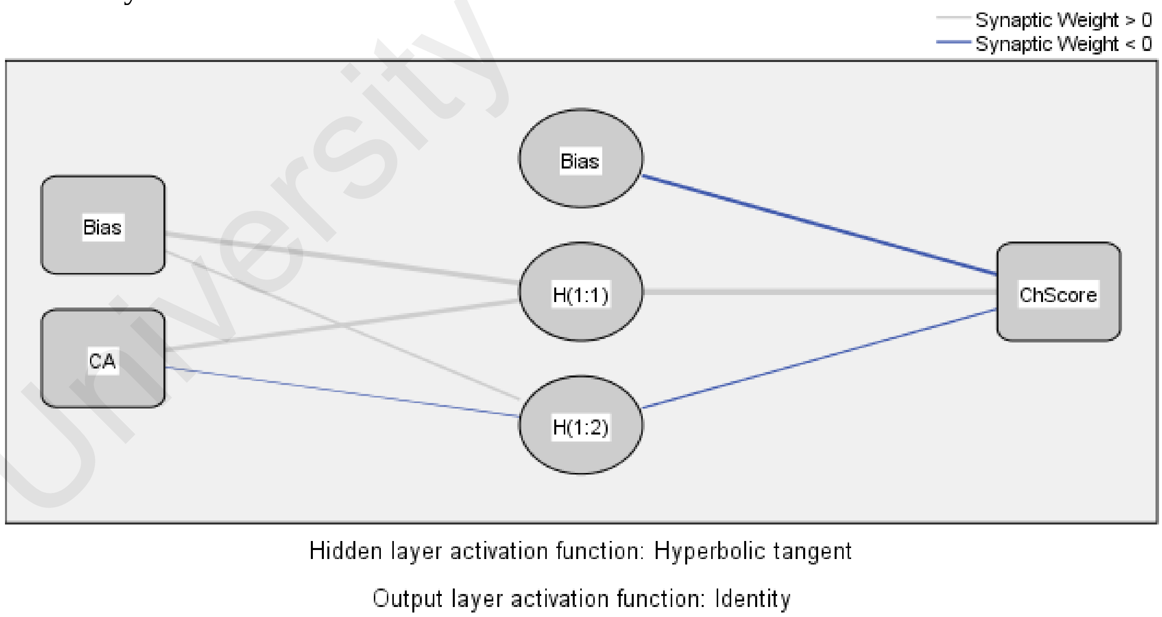

Figure 4.13b: Relationship between chronological age (CA) and modified Demirjian's score (ChScore) in Indian females based on the 8-tooth method. H: hidden layer.

Following treatment of data with ANN, the overall difference between CA and NDA based on the modified method in Indians using paired samples t-test was not significant when values were pooled together (**Table 4.48**). The difference was 0.033 years, equivalent to 0.40 months or about 12 days in males, whereas in females, it was 0.069 years, which was equivalent to 0.83 months or about 25 days. This contrasted with the differences obtained pre-ANN analysis, whereby the age of Indian children was generally under-estimated by more than 1.6 years (**Table 4.46**).

Table 4.48: Summary for comparison of chronological age and new dental age (determined by using ANN) of modified Demirjian's method in Indians

Gender	N	CA	NDA	NDA-CA	*t*	p
Male	494	11.47 ± 3.52	11.50 ± 3.62	0.033 ± 0.86	0.847	0.397*
Female	521	11.86 ± 3.6	11.93 ± 3.75	0.069 ± 0.98	1.608	0.108*

Values are mean ± SD. CA: Chronological age. NDA: New dental age. Paired samples t-test, *p>0.05.

When the overall data after being subjected to ANN analysis was sliced by age, the difference for each category of age was also not significant for the Indians (**Tables 4.49a** and **4.49b**). This was similar to those data analysed using the modified Demirjian's method for Malay and Chinese subjects.

Table 4.49a: Comparison of chronological age and new dental age based on modified Demirjian's standards as determined by using ANN in Indian males

Age	N	CA		NDA		NDA-CA		95 % CI		*t/z*	p*
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	26	5.52	0.25	5.63	0.52	0.11	0.58	-0.12	0.34	0.96	0.35
6.0-6.9	42	6.56	0.30	6.45	0.77	-0.11	0.64	-0.31	0.09	-1.12	0.27
7.0-7.9	40	7.49	0.32	7.61	0.85	0.13	0.66	-0.09	0.34	1.20	0.24
8.0-8.9	34	8.51	0.27	8.51	0.80	0.00	0.70	-0.24	0.24	0.01	0.99
9.0-9.9	38	9.54	0.30	9.62	0.83	0.07	0.77	-0.18	0.32	0.58	0.57
10.0-10.9	44	10.48	0.29	10.61	0.92	0.13	0.86	-0.13	0.39	1.01	0.32
11.0-11.9	46	11.51	0.27	11.33	1.04	-0.18	1.00	-0.48	0.12	-1.20	0.24
12.0-12.9	47	12.44	0.31	12.58	1.30	0.14	1.29	-0.24	0.52	0.74	0.46
13.0-13.9	39	13.54	0.36	13.54	1.28	0.00	1.10	-0.36	0.36	-0.01	0.99
14.0-14.9	32	14.54	0.31	14.71	0.62	0.17	0.63	-0.06	0.40	1.52	0.14
15.0-15.9	43	15.54	0.28	15.73	0.98	0.19	0.88	-0.08	0.46	1.43	0.16
16.0- 16.9	44	16.49	0.30	16.37	0.85	-0.12	0.86	-0.38	0.14	-0.93	0.36
17.0-17.9[a]	19	17.46	0.31	17.34	0.37	-0.11	0.26	-0.24	0.01	-2.09	0.04

CA: Chronological age. NDA: New dental age. Paired samples t-test. *p>0.05.
a: Based on Wilcoxon test due to small sample size.

Table 4.49b: Comparison of chronological age and new dental age based on modified Demirjian's standards as determined by using ANN in Indian females

Age	N	CA		NDA		NDA-CA		95 % CI		*t*	p*
		Mean	SD	Mean	SD	Mean	SD	Lower	Upper		
5.0-5.9	28	5.53	0.29	5.57	0.65	0.04	0.59	-0.19	0.27	0.35	0.73
6.0-6.9	34	6.52	0.30	6.49	0.65	-0.03	0.64	-0.26	0.19	-0.29	0.77
7.0-7.9	27	7.50	0.28	7.47	0.64	-0.02	0.60	-0.26	0.21	-0.21	0.84
8.0-8.9	48	8.48	0.32	8.49	0.80	0.01	0.71	-0.20	0.22	0.10	0.93
9.0-9.9	35	9.46	0.31	9.60	0.79	0.14	0.72	-0.11	0.38	1.11	0.27
10.0-10.9	44	10.49	0.27	10.53	0.82	0.04	0.79	-0.20	0.28	0.32	0.75
11.0-11.9	46	11.52	0.26	11.68	1.11	0.16	1.09	-0.16	0.49	1.01	0.32
12.0-12.9	45	12.43	0.27	12.47	1.27	0.04	1.25	-0.33	0.42	0.22	0.83
13.0-13.9	48	13.55	0.26	13.62	1.05	0.07	1.05	-0.24	0.37	0.44	0.66
14.0-14.9	45	14.46	0.25	14.68	1.27	0.22	1.26	-0.16	0.60	1.15	0.26
15.0-15.9	31	15.48	0.28	15.64	1.32	0.15	1.20	-0.29	0.59	0.72	0.48
16.0- 16.9	46	16.51	0.30	16.68	1.31	0.17	1.29	-0.22	0.55	0.88	0.38
17.0-17.9	44	17.53	0.26	17.37	0.78	-0.12	0.82	-0.36	0.13	-0.94	0.36

CA: Chronological age. NDA: New dental age. Paired samples t-test. *p>0.05.

Thus, based on the data that was subjected to ANN analysis, dental scores that accurately predicted the CA were generated (**Tables 4.50** and **4.51**), for Indian males and females respectively.

Table 4.50: Scores for modified method calculated with new formulae using ANN and dental age scales for Indian males

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	25.02	9.6	64.36	14.2	91.79
5.1	25.64	9.7	65.23	14.3	92.13
5.2	26.28	9.8	66.09	14.4	92.46
5.3	26.93	9.9	66.94	14.5	92.78
5.4	27.6	10	67.78	14.6	93.1
5.5	28.28	10.1	68.61	14.7	93.4
5.6	28.98	10.2	69.43	14.8	93.7
5.7	29.7	10.3	70.23	14.9	93.99
5.8	30.43	10.4	71.03	15	94.28
5.9	31.17	10.5	71.8	15.1	94.56
6	31.93	10.6	72.57	15.2	94.83
6.1	32.7	10.7	73.32	15.3	95.1
6.2	33.49	10.8	74.07	15.4	95.36
6.3	34.29	10.9	74.79	15.5	95.61
6.4	35.1	11	75.51	15.6	95.86
6.5	35.93	11.1	76.21	15.7	96.1
6.6	36.77	11.2	76.89	15.8	96.34
6.7	37.62	11.3	77.57	15.9	96.57
6.8	38.48	11.4	78.23	16	96.8
6.9	39.36	11.5	78.87	16.1	97.02
7	40.24	11.6	79.51	16.2	97.24
7.1	41.14	11.7	80.13	16.3	97.46
7.2	42.04	11.8	80.73	16.4	97.66
7.3	42.95	11.9	81.33	16.5	97.87
7.4	43.87	12	81.91	16.6	98.07
7.5	44.8	12.1	82.48	16.7	98.26
7.6	45.73	12.2	83.03	16.8	98.46
7.7	46.66	12.3	83.57	16.9	98.64
7.8	47.61	12.4	84.11	17	98.83
7.9	48.55	12.5	84.62	17.1	99.01
8	49.5	12.6	85.13	17.2	99.19
8.1	50.45	12.7	85.63	17.3	99.36
8.2	51.4	12.8	86.11	17.4	99.53
8.3	52.35	12.9	86.58	17.5	99.7
8.4	53.3	13	87.04	17.6	99.86
8.5	54.25	13.1	87.49	17.7	100.03
8.6	55.19	13.2	87.93	17.8	100.19
8.7	56.14	13.3	88.36	17.9	100.34
8.8	57.07	13.4	88.78	18	100.49
8.9	58.01	13.5	89.19		
9	58.94	13.6	89.59		
9.1	59.86	13.7	89.98		
9.2	60.78	13.8	90.36		
9.3	61.68	13.9	90.73		
9.4	62.58	14	91.1		
9.5	63.48	14.1	91.45		

Table 4.51: Scores for modified method calculated with new formulae using ANN and dental age scales for Indian females

Age	Dental Score	Age	Dental Score	Age	Dental Score
5	26.29	9.6	66.12	14.2	91.96
5.1	26.77	9.7	67.08	14.3	92.2
5.2	27.28	9.8	68.03	14.4	92.44
5.3	27.8	9.9	68.96	14.5	92.67
5.4	28.34	10	69.87	14.6	92.89
5.5	28.9	10.1	70.76	14.7	93.1
5.6	29.48	10.2	71.64	14.8	93.31
5.7	30.08	10.3	72.49	14.9	93.52
5.8	30.7	10.4	73.33	15	93.71
5.9	31.34	10.5	74.14	15.1	93.9
6	32.01	10.6	74.94	15.2	94.09
6.1	32.69	10.7	75.71	15.3	94.27
6.2	33.4	10.8	76.46	15.4	94.44
6.3	34.13	10.9	77.2	15.5	94.61
6.4	34.88	11	77.91	15.6	94.78
6.5	35.65	11.1	78.6	15.7	94.94
6.6	36.45	11.2	79.27	15.8	95.1
6.7	37.26	11.3	79.93	15.9	95.25
6.8	38.1	11.4	80.56	16	95.4
6.9	38.95	11.5	81.17	16.1	95.54
7	39.83	11.6	81.76	16.2	95.68
7.1	40.73	11.7	82.34	16.3	95.82
7.2	41.65	11.8	82.9	16.4	95.95
7.3	42.58	11.9	83.44	16.5	96.08
7.4	43.53	12	83.96	16.6	96.21
7.5	44.5	12.1	84.46	16.7	96.33
7.6	45.48	12.2	84.95	16.8	96.46
7.7	46.48	12.3	85.42	16.9	96.57
7.8	47.49	12.4	85.88	17	96.69
7.9	48.51	12.5	86.32	17.1	96.8
8	49.54	12.6	86.75	17.2	96.91
8.1	50.58	12.7	87.16	17.3	97.02
8.2	51.63	12.8	87.56	17.4	97.12
8.3	52.68	12.9	87.95	17.5	97.23
8.4	53.74	13	88.32	17.6	97.33
8.5	54.79	13.1	88.68	17.7	97.42
8.6	55.85	13.2	89.03	17.8	97.52
8.7	56.91	13.3	89.37	17.9	97.62
8.8	57.96	13.4	89.7	18	97.71
8.9	59.01	13.5	90.01		
9	60.06	13.6	90.32		
9.1	61.09	13.7	90.61		
9.2	62.12	13.8	90.9		
9.3	63.14	13.9	91.18		
9.4	64.14	14	91.45		
9.5	65.14	14.1	91.71		

4.2.3 Comparison between the original and modified methods

A comparison between the original and modified methods following ANN treatment was performed. As an illustration, when both methods were applied on 10-year-old Malay males, it was found that the mean difference between NDA and CA was 0.14 for the original method, whereas it was 0.07 for the modified method (**Tables 4.8a** & **4.33a**). This implied that the 8-tooth method was more accurate as the mean difference was smaller. On the other hand, when both methods were applied on 15-year-old Malay males, it was found that the mean difference between NDA and CA was -0.22 for the original method, whereas it was 0.28 for the modified method (**Tables 4.8a** & **4.33a**). It implied that the original method was more accurate compared to the modified method. It was observed that there was no clear pattern on which method was more accurate in a certain age group over the other method.

As a further illustration, when both methods were applied on 10-year-old Malay females, it was found that the mean difference between NDA and CA was -0.01 for the original method, whereas it was -0.01 for the modified method (**Tables 4.8b** & **4.33b**). When both methods were applied on 15-year-old Malay females, it was found that the mean difference between NDA and CA was -0.13 for the original method, whereas it was 0.08 for the modified method (**Tables 4.8b** & **4.33b**). Thus, there was no apparent difference between the original and modified methods in terms of accuracy in DA estimation.

4.3 Oral biology: Odontogenesis (mineralisation method)

This section served to augment the earlier sections to determine the age-related stages of mineralisation of each tooth and to obtain information on variations caused by ethnicities, genders and their position in the dental arches. In line with the objectives, this section presents results on:

a. the mean and standard deviation for the mineralisation stages of 7 and 8 left mandibular permanent teeth for both genders,

b. the pattern of tooth development within dental arches and between age groups, genders and ethnicities, and

c. the level of tooth development within dental arches between genders and ethnicities.

4.3.1 Timing of stages of mineralisation of permanent teeth using the 7- and 8-tooth method

The results were presented as the mean and standard deviation for the mineralisation stages of 7 and 8 left mandibular permanent teeth for both genders.

With the Malay subjects, the descriptive statistics on mineralisation in the 7-tooth method of the lower left side of jaw, which included mean and standard deviation for individual stages of each tooth, showed that generally, the mean ages at which tooth developmental stages were achieved were earlier in Malay girls than in boys (**Table 4.52a**). The exceptions were in the central incisors at stages G & H, first molars at stages E & G and second molars at stage H, which were mineralised earlier in boys compared to girls.

With the mineralisation in the 8-tooth method as shown in **Table 4.52b**, it was generally observed that the mean ages at which tooth developmental stages that were achieved were earlier in girls than in boys. The exceptions were in the central incisors at stages D, G & H, lateral incisors at stage D, first premolars at stage B, second premolars at stage B, as well as second molars at stages A & G and third molars at stages A, B, C & D which were mineralised earlier in boys as compared to girls. There were minor differences between the 7-tooth and 8-tooth methods due to inclusion of the third molar.

Table 4.52a: A summary of mineralisation stages of lower left mandibular teeth/developmental tooth stages in Malays based on original Demirjian's method

Sex		Males				Females			
Tooth	Stage	Mean	SD	SE	N	Mean	SD	SE	N
I_1	C					5.05	0	0	1
	D	5.29	0.20	0.04	24	5.22	0.12	0.05	6
	E	5.57	0.42	0.07	36	5.55	0.45	0.07	46
	F	6.44	0.66	0.09	58	6.27	0.66	0.11	39
	G	8.04	0.94	0.09	119	8.07	0.93	0.10	93
	H	12.08	2.20	0.11	411	12.11	2.10	0.10	403
I_2	C	5.28	0.28	0.16	3	5.05	0	0	1
	D	5.40	0.33	0.05	42	5.34	0.25	0.05	25
	E	6.19	0.67	0.08	64	6.00	0.69	0.09	61
	F	7.69	0.73	0.07	102	7.49	0.76	0.10	62
	G	9.39	1.06	0.10	108	9.25	1.08	0.11	100
	H	12.73	1.91	0.11	329	12.60	1.85	0.10	339
C	C	5.37	0.26	0.04	39	5.26	0.18	0.05	15
	D	6.64	0.90	0.08	113	6.01	0.73	0.08	78
	E	8.29	1.00	0.10	103	7.56	0.77	0.10	63
	F	10.35	1.26	0.10	160	9.59	0.95	0.08	142
	G	12.43	1.26	0.13	96	11.53	1.20	0.12	98
	H	14.31	1.15	0.10	137	13.80	1.25	0.09	192
P_1	B	5.18	0.09	0.03	7	5.18	0.00	0.00	2
	C	5.50	0.35	0.05	60	5.40	0.38	0.06	41
	D	7.22	0.87	0.08	119	6.65	0.81	0.09	81
	E	8.90	0.96	0.09	125	8.62	0.83	0.08	99
	F	10.82	1.04	0.10	101	10.46	0.99	0.10	106
	G	12.32	1.24	0.13	91	11.84	1.20	0.13	88
	H	14.29	1.13	0.09	145	13.99	1.14	0.09	171
P_2	A	5.58	0.34	0.24	2	5.00	0	0	1
	B	5.26	0.27	0.06	21	5.17	0.05	0.02	9
	C	5.89	0.66	0.08	68	5.53	0.39	0.06	48
	D	7.59	0.98	0.09	115	7.12	0.88	0.10	85
	E	9.16	0.98	0.09	124	9.03	0.99	0.10	102
	F	11.31	1.15	0.10	124	10.92	1.17	0.10	126
	G	13.07	1.28	0.14	84	12.61	1.15	0.12	96
	H	14.49	1.09	0.10	110	14.35	1.00	0.09	121
M_1	D	5.12	0.03	0.02	2				
	E	5.35	0.30	0.05	38	5.43	0.53	0.09	37
	F	6.46	0.96	0.11	80	6.15	0.70	0.09	55
	G	8.57	1.22	0.08	209	8.77	1.30	0.10	173
	H	12.86	1.80	0.10	319	12.72	1.81	0.10	323
M_2	A	5.44	0.44	0.31	2				
	B	5.22	0.18	0.06	10	5.23	0.18	0.08	5
	C	5.79	0.69	0.08	73	5.48	0.40	0.06	50
	D	7.74	0.98	0.08	164	7.58	1.17	0.10	128
	E	9.95	1.14	0.10	126	9.71	1.08	0.10	113
	F	11.63	0.91	0.11	75	11.35	1.11	0.12	79
	G	13.49	1.26	0.10	151	13.31	1.25	0.09	175
	H	15.05	0.80	0.12	47	15.05	0.67	0.11	38

I_1: Central incisor, I_2: Second incisor, C: Canine, P_1:1st premolar, P_2: 2nd premolar, M_1: 1st molar, M_2: 2nd molar, SD: standard deviation; SE: standard error.

Table 4.52b: A summary of mineralisation stages of lower left mandibular teeth/ developmental tooth stages in Malays based on modified Demirjian's method

		Males				Females			
Tooth	**Stage**	**Mean**	**SD**	**SE**	**N**	**Mean**	**SD**	**SE**	**N**
I_1	C	5.73	0	0	1	5.05	0	0	1
	D	5.37	0.32	0.06	29	5.41	0.29	0.09	11
	E	5.81	0.71	0.10	51	5.66	0.50	0.06	65
	F	6.51	0.79	0.09	86	6.44	0.80	0.09	75
	G	7.92	0.99	0.08	137	8.05	1.17	0.11	122
	H	12.86	2.91	0.13	488	12.88	2.89	0.13	503
I_2	C	5.37	0.27	0.11	6	5.05	0	0	1
	D	5.53	0.46	0.06	53	5.55	0.45	0.07	44
	E	6.34	0.78	0.08	96	6.19	0.78	0.08	97
	F	7.59	0.82	0.07	121	7.50	1.03	0.11	89
	G	9.27	1.11	0.10	114	9.04	1.20	0.11	120
	H	13.60	2.62	0.13	402	13.56	2.57	0.12	426
C	C	5.51	0.44	0.06	51	5.46	0.45	0.09	25
	D	6.68	0.95	0.08	154	6.13	0.76	0.07	122
	E	8.10	1.07	0.10	119	7.48	0.86	0.09	93
	F	10.24	1.32	0.10	170	9.39	1.06	0.08	162
	G	12.56	1.45	0.15	99	11.65	1.32	0.13	102
	H	15.68	1.57	0.11	199	14.97	1.90	0.11	273
P_1	B	5.31	0.25	0.08	10	5.37	0.19	0.08	5
	C	5.68	0.55	0.06	80	5.56	0.48	0.06	61
	D	7.14	0.95	0.08	156	6.76	0.95	0.08	133
	E	8.74	1.02	0.09	138	8.40	0.93	0.08	126
	F	10.71	1.11	0.11	107	10.41	1.04	0.10	108
	G	12.28	1.23	0.13	91	11.86	1.20	0.13	86
	H	15.65	1.54	0.11	210	15.15	1.82	0.11	258
P_2	A	5.45	0.33	0.19	3	5.32	0.29	0.16	3
	B	5.43	0.44	0.08	28	5.46	0.34	0.07	21
	C	6.01	0.75	0.08	90	5.86	0.73	0.09	72
	D	7.41	1.01	0.08	143	7.08	0.96	0.08	130
	E	9.00	1.04	0.09	142	8.82	1.01	0.09	120
	F	11.25	1.21	0.11	127	10.92	1.21	0.11	129
	G	13.16	1.49	0.16	85	12.80	1.41	0.14	103
	H	15.99	1.34	0.10	174	15.67	1.60	0.11	199
M_1	D	5.29	0.30	0.15	4				
	E	5.54	0.52	0.07	52	5.49	0.41	0.06	51
	F	6.47	0.94	0.09	111	6.30	0.80	0.08	95
	G	8.44	1.22	0.08	238	8.52	1.45	0.10	215
	H	13.80	2.48	0.13	387	13.62	2.56	0.13	416

I_1: Central incisor, I_2: Second incisor, C: Canine, P_1:1st premolar, P_2: 2nd premolar, M_1: 1st molar, M_2: 2nd molar, M_3: 3rd molar SD: standard deviation; SE: standard error.

Table 4.52b: A summary of mineralisation stages of lower left mandibular teeth/ developmental tooth stages in Malays based on modified Demirjian's method (continued)

		Males				Females			
Tooth	**Stage**	**Mean**	**SD**	**SE**	**N**	**Mean**	**SD**	**SE**	**N**
M_2	A	5.44	0.44	0.31	2	5.91	0	0	1
	B	5.55	0.58	0.14	18	5.37	0.24	0.08	9
	C	5.94	0.73	0.08	95	5.63	0.51	0.06	77
	D	7.59	1.06	0.07	205	7.43	1.11	0.08	184
	E	9.80	1.06	0.09	133	9.50	1.13	0.10	127
	F	11.63	0.91	0.11	75	11.40	1.30	0.14	85
	G	13.96	1.61	0.13	159	14.00	1.68	0.12	206
	H	16.66	0.92	0.09	105	16.61	1.25	0.13	88
M3	A	9.25	1.11	0.17	44	9.65	1.48	0.25	35
	B	10.12	1.20	0.18	46	10.23	1.44	0.19	59
	C	11.75	1.36	0.13	108	12.07	1.59	0.16	103
	D	13.37	1.43	0.16	76	13.66	1.59	0.16	102
	E	15.33	1.05	0.13	66	15.56	1.34	0.15	81
	F	16.27	1.01	0.17	37	16.53	0.73	0.14	26
	G	17.08	0.68	0.09	54	17.26	0.59	0.10	33
	H	17.79	0.16	0.09	3	17.85	0.11	0.06	3
	O	7.34	1.62	0.09	358	7.42	1.77	0.10	335

I_1: Central incisor, I_2: Second incisor, C: Canine, P_1:1st premolar, P_2: 2nd premolar, M_1: 1st molar, M_2: 2nd molar, M_3: 3rd molar SD: standard deviation; SE: standard error.

With the Chinese subjects, the descriptive statistics on mineralisation in the 7-tooth method of the lower left side of jaw, which included mean and standard deviation for individual stages of each tooth were summarised in **Table 4.52b**. Generally, the mean ages at which tooth developmental stages were achieved were earlier in Chinese girls than in boys. The exceptions were in the lateral incisors at stages D & H, first premolars at stages B & C and second premolars at stage B, E & H, first molars at stages E and second molars at stage D, which were mineralised earlier in boys compared to girls.

Table 4.52c: A summary of mineralisation stages of lower left mandibular teeth/developmental tooth stages in Chinese subjects based on original Demirjian's method

		Males				Females			
Tooth	Stage	Mean	SD	SE	N	Mean	SD	SE	N
I_1	C	5.09	0	0	1				
	D	5.26	0.24	0.09	8				
	E	5.55	0.46	0.12	16	5.51	0.42	0.10	16
	F	6.51	0.62	0.10	37	6.19	0.49	0.14	12
	G	7.99	1.08	0.13	74	7.78	0.96	0.15	40
	H	12.30	2.23	0.12	347	12.39	2.28	0.12	381
I_2	C	5.09	0	0	1				
	D	5.33	0.29	0.08	15	5.37	0.25	0.08	9
	E	6.23	0.61	0.09	42	5.92	0.50	0.12	17
	F	7.63	0.76	0.10	57	7.12	0.49	0.10	22
	G	9.15	1.15	0.13	77	8.96	0.97	0.11	72
	H	12.88	1.88	0.11	291	12.90	2.00	0.11	329
C	C	5.32	0.45	0.16	8	5.08	0.08	0.04	4
	D	6.30	0.81	0.10	62	6.16	0.65	0.12	29
	E	8.12	0.85	0.10	77	7.51	0.87	0.17	27
	F	10.17	1.15	0.11	115	9.62	1.23	0.12	100
	G	12.43	1.11	0.12	90	11.36	1.22	0.13	92
	H	14.42	1.17	0.10	131	14.14	1.29	0.09	197
P_1	B	5.00	0	0	1	5.09	0	0	1
	C	5.39	0.32	0.08	18	5.49	0.47	0.15	10
	D	6.86	0.83	0.09	81	6.49	0.74	0.13	33
	E	8.73	0.83	0.09	77	8.69	0.80	0.10	61
	F	10.74	1.14	0.12	85	10.36	1.23	0.14	79
	G	12.08	1.08	0.12	81	11.85	1.28	0.14	84
	H	14.39	1.15	0.10	140	14.23	1.29	0.10	181
P_2	B	5.05	0.09	0.04	5	5.23	0.24	0.12	4
	C	5.79	0.66	0.12	31	5.57	0.45	0.12	13
	D	7.26	0.90	0.10	75	6.96	0.80	0.14	34
	E	9.04	0.93	0.10	84	9.08	1.12	0.13	69
	F	11.09	0.98	0.10	103	10.79	1.32	0.13	99
	G	13.07	1.13	0.13	80	12.55	1.33	0.14	90
	H	14.65	1.04	0.10	105	14.56	1.11	0.09	140
M_1	E	5.33	0.31	0.07	20	5.34	0.42	0.15	8
	F	6.35	0.63	0.10	40	6.01	0.51	0.11	21
	G	8.86	1.38	0.11	160	8.81	1.28	0.12	108
	H	13.15	1.77	0.11	263	13.05	1.91	0.11	312
M_2	B	5.13	0.17	0.08	5				
	C	5.83	0.73	0.13	31	5.48	0.63	0.19	11
	D	7.61	1.01	0.10	109	7.70	1.40	0.16	78
	E	10.03	1.02	0.10	99	9.83	0.89	0.10	79
	F	11.52	0.99	0.14	52	11.20	1.09	0.15	54
	G	13.62	1.30	0.11	148	13.57	1.44	0.11	167
	H	15.18	0.57	0.09	39	14.74	1.09	0.14	60

I_1: Central incisor, I_2: Second incisor, C: Canine, P_1:1st premolar, P_2: 2nd premolar, M_1: 1st molar, M_2: 2nd molar, SD: standard deviation; SE: standard error.

With the mineralisation in the 8-tooth method as shown in **Table 4.52d**, it was generally observed that the mean ages at which tooth developmental stages were achieved were earlier in girls than in boys. The exceptions were in the central incisors at stages C & H, Lateral incisors at stage C & F, first premolars at stage B, second premolars at stage B, E & H as well as second molars at stages B & G and third molars at stages D, E & F which were mineralised earlier in boys as compared to girls. There were minor differences between the 7-tooth and 8- tooth method due to inclusion of the third molar.

Table 4.52d: A summary of mineralisation stages of lower left mandibular teeth/ developmental tooth stages in the Chinese based on modified Demirjian's method

		Males				Females			
Tooth	**Stage**	**Mean**	**SD**	**SE**	**N**	**Mean**	**SD**	**SE**	**N**
I_1	C	5.09	0	0	1	5.34	0	0	1
	D	5.40	0.30	0.09	12	5.26	0.26	0.13	4
	E	5.86	0.63	0.11	32	5.71	0.54	0.10	31
	F	6.57	0.69	0.10	52	6.39	0.63	0.12	30
	G	7.84	1.10	0.12	90	7.37	0.94	0.11	69
	H	13.17	2.95	0.14	427	13.24	3.00	0.14	479
I_2	C	5.09	0	0	1	5.18	0.22	0.16	2
	D	5.54	0.43	0.08	28	5.46	0.33	0.07	20
	E	6.41	0.68	0.09	63	6.19	0.63	0.10	40
	F	7.49	0.84	0.10	72	6.97	0.68	0.10	50
	G	8.81	1.12	0.12	84	8.75	1.01	0.11	84
	H	13.89	2.51	0.13	366	13.86	2.67	0.13	418
C	C	5.53	0.45	0.11	18	5.31	0.26	0.07	16
	D	6.49	0.88	0.09	93	6.28	0.64	0.09	55
	E	7.94	0.93	0.10	89	7.23	0.85	0.11	57
	F	9.91	1.29	0.12	115	9.32	1.23	0.12	111
	G	12.46	1.17	0.12	88	11.32	1.28	0.13	92
	H	15.55	1.70	0.12	211	15.29	1.77	0.11	283
P_1	B	5.02	0.03	0.02	2	5.10	0.08	0.04	5
	C	5.71	0.49	0.08	37	5.65	0.43	0.09	26
	D	6.91	0.85	0.08	109	6.61	0.71	0.09	67
	E	8.47	0.90	0.10	87	8.31	1.01	0.11	88
	F	10.64	1.18	0.13	79	10.22	1.26	0.14	79
	G	12.28	1.43	0.16	82	11.95	1.46	0.16	83
	H	15.45	1.72	0.12	218	15.41	1.73	0.11	266
P_2	A								
	B	5.38	0.41	0.12	12	5.41	0.49	0.14	13
	C	5.97	0.65	0.09	47	5.88	0.62	0.11	33
	D	7.21	0.90	0.09	101	6.86	0.71	0.09	66
	E	8.68	0.92	0.10	89	8.71	1.01	0.11	90
	F	11.08	1.22	0.12	99	10.81	1.50	0.15	98
	G	13.18	1.35	0.15	84	12.80	1.53	0.16	93
	H	15.81	1.56	0.12	182	15.81	1.50	0.10	221
M_1	D	5.55	0.06	0.04	2				
	E	5.55	0.46	0.08	33	5.52	0.47	0.10	23
	F	6.45	0.66	0.08	61	6.20	0.62	0.10	38
	G	8.76	1.89	0.14	181	8.35	1.63	0.13	158
	H	14.11	2.37	0.13	337	14.09	2.51	0.13	395

I_1: Central incisor, I_2: Second incisor, C: Canine, P_1:1^{st} premolar, P_2: 2^{nd} premolar, M_1: 1^{st} molar, M_2: 2^{nd} molar, M_3: 3^{rd} molar SD: standard deviation; SE: standard error.

Table 4.52d: A summary of mineralisation stages of lower left mandibular teeth/developmental tooth stages in the Chinese based on modified Demirjian's method (continued)

		Males				Females			
Tooth	Stage	Mean	SD	SE	N	Mean	SD	SE	N
M_2	A	5.04	0	0	1				
	B	5.29	0.30	0.10	8	5.35	0.31	0.18	3
	C	6.06	0.74	0.10	55	5.92	0.79	0.13	37
	D	7.46	0.89	0.08	136	7.31	1.12	0.10	119
	E	9.82	1.09	0.11	97	9.61	0.98	0.10	91
	F	11.55	0.90	0.13	50	11.21	1.10	0.15	51
	G	13.96	1.63	0.13	164	14.03	1.76	0.13	189
	H	16.63	1.03	0.10	103	16.46	1.18	0.11	124
M3	A	9.72	1.66	0.36	21	9.71	1.56	0.30	27
	B	10.31	1.16	0.16	53	10.14	0.99	0.18	29
	C	12.06	1.31	0.15	76	11.82	1.63	0.18	79
	D	13.52	1.24	0.15	68	13.72	1.61	0.17	91
	E	15.18	1.28	0.16	64	15.60	1.20	0.12	102
	F	16.37	0.97	0.15	39	16.70	1.01	0.18	30
	G	17.10	0.68	0.10	49	17.02	0.71	0.10	46
	H	17.40	0.58	0.22	7	17.39	0.12	0.09	2
	O	7.47	1.63	0.11	237	7.68	1.78	0.12	208

I_1: Central incisor, I_2: Second incisor, C: Canine, P_1:1st premolar, P_2: 2nd premolar, M_1: 1st molar, M_2: 2nd molar, M_3: 3rd molar SD: standard deviation; SE: standard error.

With the Indian subjects, the descriptive statistics on mineralisation in the 7-tooth method of the lower left side of jaw, which included mean and standard deviation for individual stages of each tooth were summarised in **Table 4.52e**. Generally, the mean ages at which tooth developmental stages were achieved were earlier in Indian girls than in boys. The exceptions were in the canine at stages H, second Premolars at stage C & D, first molars at stages G and second molars at stage D, which were mineralised earlier in boys compared to girls.

Table 4.52e: A summary of mineralisation stages of lower left mandibular teeth/ developmental tooth stages in Indians based on original Demirjian's method

		Males				Females			
Tooth	Stage	Mean	SD	SE	N	Mean	SD	SE	N
I_1	D	5.36	0.09	0.06	2				
	E	5.85	0.68	0.22	10	5.48	0.52	0.23	5
	F	6.51	0.47	0.11	19	6.11	0.54	0.15	13
	G	8.06	1.03	0.16	44	7.99	0.88	0.14	37
	H	12.56	2.09	0.12	325	12.45	2.08	0.12	327
I_2	C	5.29	0	0	1				
	D	5.53	0.44	0.20	5	5.46	0.52	0.37	2
	E	6.39	0.58	0.12	24	5.94	0.63	0.18	12
	F	7.57	0.78	0.15	28	7.31	0.81	0.16	25
	G	9.50	1.24	0.16	60	9.23	1.13	0.16	48
	H	12.98	1.86	0.11	282	12.76	1.91	0.11	295
C	C	5.49	0.30	0.15	4	5.13	0.11	0.08	2
	D	6.30	0.69	0.13	26	6.13	0.69	0.18	15
	E	8.14	1.04	0.15	46	7.49	0.91	0.19	23
	F	10.41	1.27	0.12	111	9.35	0.99	0.12	71
	G	12.36	1.15	0.13	75	11.36	1.19	0.13	86
	H	14.39	1.13	0.10	138	13.82	1.34	0.10	185
P_1	C	5.58	0.33	0.09	13	5.25	0.27	0.12	5
	D	7.06	0.64	0.10	39	6.56	0.60	0.12	23
	E	9.33	1.18	0.15	62	8.58	0.69	0.10	50
	F	10.87	1.17	0.13	80	10.54	1.15	0.14	72
	G	12.26	0.85	0.11	57	11.83	1.08	0.13	71
	H	14.32	1.17	0.10	149	14.08	1.17	0.09	161
P_2	B	5.29	0.29	0.17	3	5.09	0	0	1
	C	5.67	0.27	0.08	12	5.80	0.57	0.17	11
	D	7.33	0.94	0.15	40	7.52	1.31	0.26	25
	E	9.48	1.25	0.15	69	8.97	0.94	0.13	55
	F	11.23	1.18	0.12	96	10.94	1.26	0.14	83
	G	12.79	1.04	0.13	62	12.36	1.22	0.14	81
	H	14.63	0.98	0.09	118	14.39	1.02	0.09	126
M_1	E	5.40	0.24	0.08	8	5.15	0.08	0.03	5
	F	6.50	0.92	0.26	13	6.17	0.45	0.15	9
	G	8.77	1.55	0.15	101	8.82	1.33	0.14	91
	H	13.00	1.87	0.11	278	12.96	1.80	0.11	277
M_2	C	5.74	0.69	0.20	12	5.45	0.45	0.16	8
	D	7.39	0.99	0.13	55	7.80	1.13	0.16	53
	E	9.96	1.16	0.12	90	9.82	0.91	0.11	69
	F	11.69	1.08	0.14	60	11.51	1.11	0.16	51
	G	13.37	1.18	0.11	121	13.24	1.28	0.10	150
	H	15.12	0.68	0.09	62	15.02	0.73	0.10	51

I_1: Central incisor, I_2: Second incisor, C: Canine, P_1:1st premolar, P_2: 2nd premolar, M_1: 1st molar, M_2: 2nd molar, SD: standard deviation; SE: standard error.

With the mineralisation in the 8-tooth method as shown in **Table 4.52f**, it was generally observed that the mean ages at which tooth developmental stages were achieved were earlier in girls than in boys. The exceptions were in the central incisors at stages H, Lateral incisors at stage H, first molars at stage H, second molars at stage B, C, D, E, F, G & H and third molars at stages D, E, F & G which were mineralised earlier in boys as compared to girls. There were minor differences between the 7-tooth and 8- tooth method due to inclusion of the third molar.

Table 4.52f: A summary of mineralisation stages of lower left mandibular teeth/ developmental tooth stages in Indians based on modified Demirjian's method

		Males				Females			
Tooth	Stage	Mean	SD	SE	N	Mean	SD	SE	N
I_1	C								
	D	5.52	0.22	0.10	5	5.34	0.25	0.13	4
	E	5.96	0.59	0.11	31	5.63	0.48	0.13	14
	F	6.62	0.51	0.09	32	6.31	0.62	0.11	34
	G	8.02	1.03	0.14	52	7.90	1.07	0.14	60
	H	12.90	2.73	0.14	374	13.18	2.82	0.14	409
I_2	C	5.29	0	0	1				
	D	5.84	0.41	0.10	19	5.47	0.29	0.09	10
	E	6.43	0.65	0.10	45	6.16	0.68	0.12	34
	F	7.60	0.95	0.15	39	7.37	1.07	0.15	48
	G	9.13	1.33	0.16	70	8.91	1.19	0.15	60
	H	13.51	2.41	0.13	320	13.62	2.57	0.13	369
C	C	5.93	0.58	0.16	14	5.51	0.42	0.16	7
	D	6.32	0.67	0.09	52	6.21	0.78	0.13	39
	E	7.97	1.04	0.13	64	7.29	0.94	0.14	47
	F	10.18	1.22	0.11	114	9.07	1.10	0.12	85
	G	12.32	1.36	0.15	79	11.37	1.35	0.14	87
	H	15.26	1.54	0.12	171	14.82	1.95	0.12	256
P_1	B								
	C	5.98	0.57	0.09	38	5.65	0.50	0.11	22
	D	7.00	0.79	0.11	56	6.65	0.74	0.10	53
	E	8.86	1.15	0.13	77	8.39	0.75	0.09	67
	F	10.71	1.13	0.13	78	10.31	1.09	0.13	75
	G	12.12	0.98	0.12	61	11.97	1.34	0.16	71
	H	15.15	1.58	0.12	184	15.09	1.80	0.12	233
P_2	A					5.83	0.97	0.56	3
	B	5.55	0.27	0.09	9	5.31	0.31	0.22	2
	C	6.19	0.70	0.11	40	6.06	0.70	0.12	34
	D	7.36	0.97	0.13	52	7.26	1.21	0.17	52
	E	9.05	1.21	0.14	79	8.80	0.94	0.11	70
	F	11.09	1.18	0.12	97	10.78	1.24	0.14	81
	G	12.88	1.29	0.16	68	12.64	1.40	0.15	84
	H	15.56	1.35	0.11	149	15.46	1.66	0.12	195

I_1: Central incisor, I_2: Second incisor, C: Canine, P_1:1^{st} premolar, P_2: 2^{nd} premolar, M_1: 1^{st} molar, M_2: 2^{nd} molar, M_3: 3^{rd} molar SD: standard deviation; SE: standard error.

Table 4.52f: A summary of mineralisation stages of lower left mandibular teeth/ developmental tooth stages in Indians based on modified Demirjian's method (continued)

		Males				Females			
Tooth	Stage	Mean	SD	SE	N	Mean	SD	SE	N
M_1	D	5.43	0	0	1				
	E	5.76	0.47	0.11	19	5.51	0.52	0.13	17
	F	6.46	0.83	0.14	37	6.37	0.62	0.11	33
	G	8.55	1.58	0.14	123	8.55	1.42	0.13	123
	H	13.56	2.38	0.13	314	13.86	2.43	0.13	348
M_2	A					5.01	0	0	1
	B	5.63	0.14	0.07	4	5.92	0.61	0.12	25
	C	6.06	0.61	0.11	30	7.40	1.17	0.12	93
	D	7.23	0.97	0.10	87	9.55	0.99	0.11	79
	E	9.79	1.07	0.11	95	11.42	1.08	0.15	49
	F	11.54	1.12	0.15	59	13.44	1.46	0.11	162
	G	13.63	1.43	0.13	129	16.48	1.09	0.10	112
	H	16.24	0.97	0.10	90	5.01	0	0	1
M3	A	9.21	1.39	0.28	25	9.12	0.94	0.19	25
	B	10.26	1.41	0.22	41	10.25	1.44	0.24	36
	C	11.59	1.33	0.15	77	11.27	1.39	0.17	68
	D	13.00	1.59	0.18	82	13.27	1.54	0.16	96
	E	15.00	1.20	0.15	60	15.06	1.51	0.17	81
	F	15.94	0.73	0.15	25	16.37	0.93	0.16	35
	G	16.60	0.63	0.12	29	17.02	0.62	0.10	37
	H	17.50	0.47	0.14	12	17.71	0.24	0.17	2
	O	7.45	1.67	0.14	143	7.68	1.92	0.16	141

I_1: Central incisor, I_2: Second incisor, C: Canine, P_1:1st premolar, P_2: 2nd premolar, M_1: 1st molar, M_2: 2nd molar, M_3: 3rd molar SD: standard deviation; SE: standard error.

4.3.2 Pattern of tooth development within dental arches and between age groups, gender and ethnic groups

This section analysed a total of 4614 samples. These samples included all those which were deemed as outliers based on statistical analysis, as well as those samples which had more than one tooth missing in the lower jaw, and were thus excluded for forensic analysis, but which fulfilled the overall inclusion criteria for this study.

Overall, Malays represented the largest group followed by Chinese and then Indians (**Table 4.53**).

Table 4.53: Demographics of study subjects for mineralisation patterns

Ethnicity	Male	Female	Total (%)
Malay	928 (20.1)	942 (20.4)	1870 (40.5)
Chinese	742 (16.1)	747 (16.2)	1489 (32.3)
Indian	631 (13.7)	624 (13.5)	1255 (27.2)
Total	2301(49.9)	2313 (50.1)	4614 (100.0)

The number of samples for each age group was consistent, ranging from 317 to 390 subjects per age group, indicating that groups segregated by sex (**Table 4.54a**), ethnicity (**Table 4.54b**) and by both ethnicity and sex (**Table 4.54c**) were sufficiently represented for the analysis of mineralisation. The males and females were represented in approximately equal proportions of 50%.

Table 4.54a: Distribution of samples in each age group by sex

			Age													Total
			5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	
Sex	Male	Count	180	182	206	202	170	190	159	183	155	153	176	157	188	2301
		% of total	3.9	3.9	4.5	4.4	3.7	4.1	3.4	4.0	3.4	3.3	3.8	3.4	4.1	49.9
	Female	Count	171	172	152	188	178	175	181	179	194	164	195	174	190	2313
		% of total	3.7	3.7	3.3	4.1	3.9	3.8	3.9	3.9	4.2	3.6	4.2	3.8	4.1	50.1
Total		Count	351	354	358	390	348	365	340	362	349	317	371	331	378	4614
		% of total	7.6	7.7	7.8	8.5	7.5	7.9	7.4	7.8	7.6	6.9	8.0	7.2	8.2	100.0

Table 4.54b: Distribution of samples in each age group by ethnicity

			Age													Total
			5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	
Ethnicity	Malay	Count	195	144	179	173	153	139	135	127	134	114	116	134	127	**1870**
		% of total	4.2	3.1	3.9	3.7	3.3	3.0	2.9	2.8	2.9	2.5	2.5	2.9	2.8	**40.5**
	Chinese	Count	96	126	106	122	98	123	99	126	107	103	142	99	142	**1489**
		% of total	2.1	2.7	2.3	2.6	2.1	2.7	2.1	2.7	2.3	2.2	3.1	2.1	3.1	**32.3**
	Indian	Count	60	84	73	95	97	103	106	109	108	100	113	98	109	**1255**
		% of total	1.3	1.8	1.6	2.1	2.1	2.2	2.3	2.4	2.3	2.2	2.4	2.1	2.4	**27.2**
Total		Count	351	354	358	390	348	365	340	362	349	317	371	331	378	**4614**
		% of total	7.6	7.7	7.8	8.5	7.5	7.9	7.4	7.8	7.6	6.9	8.0	7.2	8.2	**100.0**

Table 4.54c: Distribution of samples in each age group by ethnicity and sex

				Age												
				5.00	**6.00**	**7.00**	**8.00**	**9.00**	**10.00**	**11.00**	**12.00**	**13.00**	**14.00**	**15.00**	**16.00**	**17.00**
Ethnicity	**Malay**	**Sex**	**Male**	101	74	96	97	81	65	67	62	58	48	52	61	66
			% of total	52	51	54	56	53	47	50	49	43	42	45	46	52
			Female	94	70	83	76	72	74	68	65	76	66	64	73	61
			% of total	48	49	46	44	47	53	50	51	57	58	55	54	48
	Chinese	**Sex**	**Male**	51	60	66	65	41	73	41	66	47	53	63	47	69
			% of total	53	48	62	53	42	59	41	52	44	51	44	47	49
			Female	45	66	40	57	57	50	58	60	60	50	79	52	73
			% of total	47	52	38	47	58	41	59	48	56	49	56	53	51
	Indian	**Sex**	**Male**	28	48	44	40	48	52	51	55	50	52	61	49	53
			% of total	47	57	60	42	49	50	48	50	46	52	54	50	49
			Female	32	36	29	55	49	51	55	54	58	48	52	49	56
			% of total	53	43	40	58	51	50	52	50	54	48	46	50	51

4.3.2.1 Pattern of tooth development within dental arches in Malays by age

In the Malays, comparison of tooth development within dental arches and between age groups shows the mixed development between maxillary and mandibular arches (**Tables 4.55** and **4.56** for males and females respectively).

The teeth generally developed a little bit earlier in females than in males. The mandibular permanent teeth developed more quickly than the maxillary permanent teeth, in both genders. In addition, a difference was observed between the right and left sides of the jaws, but it differed by one stage and not necessarily in all teeth. This is illustrated in the case of the 5-year-old Malay males, in which the canine on the right side (13) was at stage C whereas on the left side (23) it was at stage D. On the other hand, in the lower jaw, the mineralisation of the canine on the right (34) and left sides was similar at stage C.

In Malay males, the mandibular central and lateral incisors completed development at 9 years while the maxillary central incisors completed development later at 10 years and lateral incisors at 11 years. In Malay females, the mandibular and maxillary central and lateral incisors completed development at 10 years. The mandibular and maxillary canines, first premolars and mandibular second premolars completed development at 13 years and maxillary second premolars at 14 years in males when compared to 12 years and 13 years in females respectively. In both genders, the mandibular and maxillary first molars completed development at 10 years.

In Malay males, the maxillary and mandibular third molars completed development of the crown at 11 and 13 years respectively; with Malay females, the maxillary and mandibular third molars would have completed development of the crown earlier at 10 and 12 years, respectively. However, the third molar root portion would continue developing in both genders. The mandibular and maxillary second molars completed development at 15 years in males and 16 years in females.

Table 4.55: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay males

Age	n																		
	n	**Max**	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	1	40.6	45	55.7	72.3	46.5	67.4	64.6	64.6	67.7	45	75.2	57	44.6	40.6	1
Age 5	**101**		**Stage**	A	D (B-E)	E (D-G)	C (B-E)	C (B-E)	C (C-E)	D (C-E)	D (C-F)	D (C-F)	D (C-E)	D (C-E)	C (B-E)	C (B-E)	E (D-G)	D (B-E)	A
		Man	**Stage**	B	C (B-D)	E (D-G)	C (A-D)	C (B-E)	C (C-E)	D (C-F)	E (D-G)	E (D-G)	D (C-F)	C (C-E)	C (B-E)	C (A-D)	E (D-G)	C (A-D)	O
			%	1	56.4	48	49.5	57.4	47	50.5	38.1	37.8	49.5	49	59.4	50.5	45.5	58.4	0
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
	n	**Max**	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	0	74.3	43.2	66.2	72.2	60.8	52.8	43.1	40.8	52.1	60.8	68.5	64.4	48.6	75.7	0
Age 6	**74**		**Stage**	O	D (C-E)	F (E-G)	D (C-E)	D (C-E)	D (C-E)	D (C-E)	E (D-F)	E (D-F)	D (C-E)	D (C-E)	D (C-E)	D (C-E)	G (E-G)	D (C-E)	O
		Man	**Stage**	O	D (B-D)	F (E-G)	D (B-E)	D (C-E)	D (C-E)	E (D-F)	F (D-G)	F (D-G)	E (D-F)	D (C-E)	D (C-E)	D (B-E)	F (E-G)	D (B-D)	O
			%	0	56.8	62.2	50	67.1	76.4	57.1	58.6	56.3	57.1	80.8	68.5	47.3	62.2	56.8	0
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.55: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay males (continued)

Age	n	Arch																	
Age 7	96	Max	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	2.1	77.1	80.2	68.4	66.7	56.2	63.8	43.8	43.8	62.1	56.2	67.7	67.7	84.42	70.8	2.1
			Stage	C	D (C-E)	G (F-H)	D (C-F)	D (C-E)	E (D-F)	E (D-G)	F (E-H)	F (E-H)	E (D-G)	E (D-F)	D (C-E)	D (C-F)	G (F-H)	D (C-E)	C
		Man	Stage	A	D (C-E)	G (F-H)	D (C-F)	D (C-F)	D (D-F)	F (E-H)	G (E-H)	G (E-H)	F (E-H)	D (D-F)	D (C-F)	D (C-F)	G (F-H)	D (C-E)	A
			%	4.2	84.4	75	64.6	64.6	53.7	57.6	59.6	61.1	57.6	53.1	63.5	65.6	74	83.3	5.2
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
Age 8	97	Max	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	10.4	57.7	85.6	49.5	55.3	67	57.3	50.5	49.5	56.4	66	59.1	54.3	86.6	49.5	7.2
			Stage	A (A-C)	D (D-F)	G (F-H)	E (D-F)	E (D-F)	E (D-F)	F (E-G)	G (E-H)	G (E-H)	F (E-G)	E (D-F)	E (D-F)	E (D-F)	G (F-H)	D (D-F)	B (A-C)
		Man	Stage	A (A-C)	D (C-F)	G (F-H)	E (C-F)	E (D-F)	E (D-F)	G (E-H)	H (F-H)	G (F-H)	G (E-H)	E (D-F)	E (D-F)	E (C-F)	G (F-H)	D (C-F)	A (A-C)
			%	15.5	62.9	78.4	53.6	57.3	54.7	45.8	48.5	49	48.5	54.2	53.6	52.6	82.5	60.8	15.5
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.55: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay males (continued)

Age	n	Arch																	
Age 9	81	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	17.3	63	63	56.2	48.1	70.4	38.8	53.1	53.1	36.2	72.8	50.6	60.5	64.2	65.4	18.5
			Stage	B (A-D)	E (D-F)	G (F-H)	E (D-F)	E (D-G)	F (E-F)	F (D-H)	G (F-H)	G (F-H)	G (E-H)	F (E-F)	E (D-G)	E (D-G)	G (F-H)	E (D-F)	B (A-C)
		Man	Stage	B (A-D)	E (D-F)	G (F-H)	E (D-G)	E (D-G)	F (D-G)	H (F-H)	H (F-H)	H (F-H)	H (F-H)	F (E-G)	E (D-G)	E (D-G)	G (F-H)	E (D-F)	B (A-C)
			%	24.7	63	59.3	63	50.6	65.8	47.5	75.3	77.8	45.7	69.2	55	58	63	66.7	18.5
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 10	65	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	18.8	55.4	56.9	39.1	38.5	78.1	43.8	53.8	53.8	42.2	78.5	45.3	39.7	61.5	60	20.3
			Stage	D (A-D)	E (D-G)	G (G-H)	F (D-G)	F (E-H)	F (E-G)	G (F-H)	H (F-H)	H (G-H)	G (F-H)	F (E-G)	F (E-H)	E (D-G)	H (G-H)	E (D-G)	C (A-D)
		Man	Stage	C (A-D)	E (D-G)	H (G-H)	F (D-G)	F (E-G)	F (E-G)	H (F-H)	H (G-H)	H (G-H)	H (F-H)	F (E-G)	F (E-G)	F (D-G)	H (G-H)	E (D-G)	C (A-D)
			%	41.5	52.3	67.7	46.2	49.2	70.5	62.5	87.7	87.7	63.1	73.8	55.4	53.8	63.1	56.9	34.4
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.55: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay males (continued)

Age	n	Arch																	
Age 11	67	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	35.8	35.8	83.6	43.3	46.3	55.2	69.7	87.9	82.1	73.1	50.7	40.3	40.3	82.1	35.8	40.3
			Stage	D (B-E)	G (E-G)	H (G-H)	F (E-H)	G (E-H)	F (F-H)	H (F-H)	H (G-H)	H (G-H)	H (F-H)	F (E-H)	G (E-H)	F (E-H)	G (G-H)	G (D-G)	D (B-E)
		Man	Stage	C (A-D)	F (E-G)	H (G-H)	F (E-H)	G (E-H)	F (F-H)	H (G-H)	H (G-H)	H (G-H)	H (G-H)	F (F-H)	F (E-H)	F (E-H)	H (G-H)	F (E-G)	C (A-D)
			%	41.8	44.8	86.6	60.6	40.9	48.4	79.1	95.5	95.1	85.1	46.3	46.3	61.2	92.5	43.3	44.8
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 12	62	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	50	64.5	95.2	45.6	51.7	59	74.2	85.5	85.5	74.2	58.3	50.8	47.5	96.8	67.7	52.2
			Stage	D (B-E)	G (E-H)	H (G-H)	G (F-H)	G (F-H)	G (F-H)	H (G-H)	H (G-H)	H (G-H)	H (G-H)	G (F-H)	G (F-H)	G (F-H)	G (G-H)	G (E-H)	D (B-E)
		Man	Stage	C (B-E)	G (E-H)	H (G-H)	F (F-H)	G (F-H)	G (F-H)	H (G-H)	H	H	H (G-H)	G (F-H)	G (F-H)	G (F-H)	H (G-H)	G (E-H)	C (B-E)
			%	40.3	59.7	95.2	45.2	54.8	47.5	96.8	100	100	95.2	52.5	50	41.9	95.2	50	50
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.55: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay males (continued)

	n																		
Age 13	58	Max	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	45.6	82.8	96.6	53.4	70.7	51.7	87.7	96.6	96.6	91.2	51.7	69	49.1	96.6	84.5	48.2
			Stage	D (C-E)	G (F-H)	H (G-H)	H (F-H)	H (G-H)	H (F-H)	H (G-H)	H	H	H	H (F-H)	H (G-H)	G (F-H)	H (G-H)	G (E-H)	D (C-E)
		Man	**Stage**	D (C-E)	G (F-H)	H (G-H)	H (F-H)	H (F-H)	H (F-H)	H	H	H	H	H (F-H)	H (F-H)	G (F-H)	H	G (F-H)	D (C-E)
			%	43.9	81	87.9	41.4	65.5	51.7	96.6	98.3	96.6	94.8	60.3	60.3	39.7	91.4	77.6	42.9
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
Age 14	48	Max	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	40.4	70.8	97.9	74.5	89.4	66	91.7	95.7	93.8	95.8	70.8	93.5	77.1	97.9	68.8	40.4
			Stage	E (D-G)	G (G-H)	H	H (G-H)	H (G-H)	H (G-H)	H	H	H	H	H (F-H)	H (G-H)	H (G-H)	H	G (G-H)	E (D-G)
		Man	**Stage**	E (C-G)	G (G-H)	H	H (F-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	H (F-H)	H	G (G-H)	E (C-G)
			%	45.8	70.8	97.9	72.9	93.8	80.9	100	100	100	100	83.3	93.8	70.8	95.8	70.8	43.8
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.55: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay males (continued)

	n																		
Age 15	52	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	23.1	55.8	98.1	98.1	94.2	86.5	98	96	98.1	96.1	84.6	94.2	88.5	94.1	68.6	26
			Stage	G (C-G)	H (G-H)	H	H (G-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	H (G-H)	H	H (G-H)	E (D-G)
		Man	Stage	E (C-G)	H (G-H)	H	H (G-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H	H (G-H)	H	H (G-H)	E (C-G)
			%	34.6	59.6	98.1	88.5	92.3	90.4	98.1	98.1	96.2	96.2	88.5	88.5	82.7	92.3	59.6	37.3
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

	n																		
Age 16	61	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	25	68.9	100	90.2	93.4	93.4	98.4	91.8	93.4	98.4	95.1	96.7	91.7	96.7	75.4	31.1
			Stage	G (D-H)	H (G-H)	H	H (G-H)	H	H (G-H)	H	H	H	H	H	H	H (G-H)	H	H (G-H)	G (D-H)
		Man	Stage	F (D-G)	H (G-H)	H	H	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H	H (G-H)	H	H (G-H)	E (D-G)
			%	31.1	54.1	98.4	95.1	95.1	96.6	100	100	100	100	90.2	91.7	90.2	96.7	55.7	33.3
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.55: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay males (continued)

	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Age 17	66		%	52.3	84.8	97.0	97.0	97.0	95.5	92.4	90.9	92.4	89.4	93.9	97.0	97.0	97.0	83.3	59.4
			Stage	G (E-G)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (D-H)
		Man	Stage	G (E-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (E-H)
			%	59.1	74.2	98.5	95.5	97.0	95.5	98.5	98.5	97.0	98.5	93.9	95.5	95.5	95.4	81.8	57.6
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.56: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay females

	n																		
	n	**Max**	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	100	51.1	46.8	64.1	74.5	61.3	73.4	76.6	76.6	73.4	58.5	71.3	62.4	45.7	55.6	100
Age 5	**94**		**Stage**	O	D (B-D)	F (D-G)	C (B-D)	C (C-D)	D (C-E)	D (C-E)	D (C-E)	D (C-E)	D (C-E)	D (C-E)	C (C-D)	C (B-D)	F (D-G)	D (B-D)	O
		Man	**Stage**	O	C (B-D)	E (E-G)	C (B-D)	C (B-D)	D (C-E)	E (D-F)	E (D-G)	E (D-G)	E (D-F)	D (C-E)	C (B-D)	C (A-D)	E (E-G)	C (B-D)	O
			%	100	61.7	54.3	54.8	59.6	72	53.3	56.5	57.6	51.6	67.7	54.3	51.1	53.2	63.8	100
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

	n	**Max**	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	1.4	74.3	47.8	75.0	73.9	47.1	51.5	60.0	59.4	50.0	45.7	73.5	70.1	47.1	75.7	1.4
Age 6	**70**		**Stage**	B	D (C-E)	G (E-G)	D (C-E)	D (C-E)	E (D-F)	E (D-F)	E (D-G)	E (D-G)	E (D-F)	D (C-F)	D (C-E)	D (C-E)	G (E-G)	D (C-E)	B
		Man	**Stage**	B	D (C-E)	F (E-G)	D (B-E)	D (C-E)	D (D-F)	E (D-G)	F (E-H)	F (E-H)	E (D-G)	D (D-F)	D (C-E)	D (B-E)	F (E-G)	D (C-E)	B
			%	1.4	68.6	52.9	60.0	67.1	57.1	48.5	44.1	44.1	46.3	65.7	67.1	58.6	57.1	70.0	1.4
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.56: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay females (continued)

	n	Arch		18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Age 7	83	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	2.4	78.3	79.5	67.1	63.7	58.5	49.4	55.4	55.4	49.4	62.2	63.3	66.7	80.7	74.7	2.4
			Stage	B (A-B)	D (D-E)	G (E-G)	D (D-F)	D (D-F)	E (D-F)	E (D-G)	F (D-G)	F (D-G)	E (D-G)	E (D-F)	D (D-F)	D (D-F)	G (E-G)	D (D-E)	B
		Man	Stage	A (A-B)	D (D-E)	G (F-H)	D (C-E)	D (D-F)	E (D-F)	F (E-H)	G (F-H)	G (F-H)	F (E-H)	E (D-F)	D (D-F)	D (C-E)	G (F-H)	D (D-E)	A (A-B)
			%	9.6	80.7	71.1	63.9	54.2	50.0	47.5	53.0	54.2	46.9	53.0	54.2	68.7	71.1	81.9	7.2
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 8	76	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	13.2	48.7	81.6	63.2	65.3	55.3	57.3	47.4	46.1	58.7	59.2	61.8	67.1	81.6	51.3	9.2
			Stage	B (A-D)	E (D-F)	G (F-H)	E (D-F)	E (D-G)	F (D-G)	F (E-H)	G (F-H)	G (F-H)	F (E-H)	F (D-G)	E (D-G)	E (C-F)	G (F-H)	D (D-F)	B (A-D)
		Man	Stage	B (A-C)	D (D-F)	G (F-H)	E (C-F)	E (D-F)	F (E-G)	G (F-H)	G (F-H)	G (F-H)	G (F-H)	F (E-G)	E (D-G)	E (C-F)	G (F-H)	D (D-F)	B (A-C)
			%	13.3	48.7	75.0	64.5	72.4	57.5	41.1	50.0	50.0	52.6	60.5	73.7	69.7	77.6	51.3	14.7
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.56: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay females (continued)

Age	n	Arch	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Age 9	72	Max	%	20.8	61.1	58.3	51.4	41.2	71.8	44.3	56.9	58.3	43.7	73.6	44.3	52.2	59.2	62.5	23.6
			Stage	B (A-D)	E (D-F)	G (F-H)	E (D-G)	F (D-G)	F (E-G)	G (E-H)	G (F-H)	G (F-H)	G (E-H)	F (D-G)	F (D-G)	E (D-G)	G (F-H)	E (D-F)	B (A-D)
		Man	Stage	B (A-C)	E (D-F)	G (F-H)	E (D-F)	F (D-G)	F (D-G)	G (F-H)	H (F-H)	H (F-H)	G (F-H)	F (D-G)	F (D-G)	E (D-F)	G (F-H)	E (D-F)	B (A-C)
			%	26.4	58.3	65.3	45.8	47.9	75.4	50.0	75	75.0	55.6	76.1	50.7	43.1	65.3	63.9	27.8
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Age	n	Arch	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Age 10	74	Max	%	23.3	45.9	63.5	43.1	49.3	56.8	56.2	59.5	59.5	50.0	61.6	45.1	47.2	63.5	43.2	24.7
			Stage	D (A-D)	E (D-G)	H (G-H)	F (D-G)	G (D-H)	F (F-H)	H (F-H)	H (G-H)	H (G-H)	H (F-H)	F (F-H)	G (D-H)	F (D-G)	H (G-H)	F (D-G)	D (A-D)
		Man	Stage	C (A-D)	E (D-G)	H (G-H)	F (D-G)	F (F-H)	F (E-H)	H (G-H)	H (G-H)	H (G-H)	H (G-H)	F (E-H)	F (E-H)	F (D-G)	H (G-H)	E (D-G)	C (A-D)
			%	31.5	43.2	62.2	63.5	55.4	52.9	86.5	97.3	94.6	79.7	59.7	57.5	59.5	64.9	43.2	33.3
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.56: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay females (continued)

	n																		
	n	**Max**	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
Age 11	**68**		**%**	46.3	48.5	88.2	45.5	52.9	45.5	85.3	92.6	86.8	82.4	45.6	49.3	54.4	85.3	48.5	50.0
			Stage	D (B-E)	G (D-H)	H (G-H)	G (E-H)	G (F-H)	G (F-H)	H (G-H)	H (G-H)	H (G-H)	H (G-H)	G (F-H)	G (E-H)	G (E-H)	H (G-H)	G (D-H)	D (B-E)
		Man	**Stage**	C (A-D)	G (D-G)	H (G-H)	F (E-H)	G (F-H)	G (F-H)	H (F-H)	H (F-H)	H (G-H)	H (F-H)	G (F-H)	G (F-H)	F (E-H)	H (G-H)	F (E-G)	C (A-E)
			%	35.3	42.6	89.7	54.4	45.6	45.5	92.6	95.6	94.1	85.3	50	42.6	53.7	91.2	48.5	44.1
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

	n	**Max**	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
Age 12	**65**		**%**	50.8	80.0	95.4	49.2	58.5	51.6	93.8	98.5	95.2	90.8	51.6	56.9	52.3	90.8	73.8	52.3
			Stage	D (C-G)	G (F-H)	H (G-H)	G (F-H)	H (F-H)	H (F-H)	H (G-H)	H	H (G-H)	H (G-H)	H (F-H)	H (F-H)	G (F-H)	H	G (F-H)	D (B-E)
		Man	**Stage**	D (B-E)	G (F-H)	H (G-H)	G (F-H)	H (F-H)	H (G-H)	H (G-H)	H	H	H (G-H)	H (G-H)	H (F-H)	G (F-H)	H (G-H)	G (F-H)	D (B-E)
			%	36.9	69.2	95.4	49.2	54.7	66.2	93.8	100.0	100.0	93.8	60.9	49.2	46.2	92.3	72.3	34.4
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.56: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay females (continued)

	n																		
	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	24.0	67.1	93.4	65.3	78.7	60.0	86.8	97.4	96.1	86.8	63.2	71.1	65.8	93.4	72.0	38.7
Age 13	76		Stage	E (C-G)	G (F-H)	H	H (F-H)	H (F-H)	H (F-H)	H	H	H	H	H (F-H)	H (F-H)	H (F-H)	H	G (F-H)	D (B-F)
		Man	Stage	D (B-E)	G (F-H)	H (G-H)	H (F-H)	H (F-H)	H (G-H)	H (G-H)	H	H	H (G-H)	H (G-H)	H (F-H)	H (F-H)	H (G-H)	G (F-H)	D (B-E)
			%	42.1	71.1	93.4	46.7	69.7	76.3	93.4	96.1	96.1	90.8	78.9	76.3	50.0	96.1	72.4	44.0
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

	n																		
	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	45.3	54.5	100.0	78.8	96.9	97	95.5	100	98.5	93.8	86.4	95.4	84.8	98.5	57.6	43.8
Age 14	66		Stage	E (C-G)	G (G-H)	H	H (G-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	H (G-H)	H	G (G-H)	E (C-G)
		Man	Stage	E (C-F)	G (G-H)	H (G-H)	H (F-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	H (G-H)	H (G-H)	G (G-H)	E (C-F)
			%	43.1	62.1	97	83.3	90.9	96.9	95.5	98.5	98.5	97	96.9	92.2	72.7	98.5	69.7	42.4
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.56: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay females (continued)

Age	n	Arch																	
Age 15	n	Max	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
	64		**%**	27	48.4	96.9	85.7	90.5	85.7	95.3	92.2	93.7	95.2	89.1	92.2	73.4	96.9	48.4	28.6
			Stage	E (C-G)	G (G-H)	H	H (G-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	H (G-H)	H	G (G-H)	E (C-G)
		Man	**Stage**	E (C-G)	G (G-H)	H (G-H)	H (G-H)	H	H	H	H	H	H	H	H	H (G-H)	H (G-H)	G (G-H)	E (C-G)
			%	38.1	60.9	90.5	82.8	92.2	95.2	95.3	96.9	96.9	93.8	95.3	95.3	76.6	89.1	59.4	43.8
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
Age 16	n	Max	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
	73		**%**	38	75.3	100.0	89	97.3	94.5	100	100	100	98.6	93.2	97.2	90.3	98.6	68.5	31.9
			Stage	E (D-G)	H (G-H)	H	H (G-H)	H	H	H	H	H	H	H (G-H)	H	H (G-H)	H	H (G-H)	E (D-G)
		Man	**Stage**	E (D-G)	H (G-H)	H	H (G-H)	H	H	H	H	H	H	H	H	H (G-H)	H	H	E (D-G)
			%	36.1	54.8	98.6	89	100.0	100.0	97.3	100	100	98.6	98.6	98.6	86.3	98.6	58.9	33.8
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.56: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Malay females (continued)

	n																		
		Max	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
Age 17	**61**		**%**	38.3	78.7	98.4	98.4	91.8	98.4	96.7	96.7	98.4	98.4	100.0	98.4	95.1	100	88.5	46.7
			Stage	G (E-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (E-H)
		Man	**Stage**	G (D-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H	G (D-H)
			%	36.1	75.4	98.3	95.1	93.4	95.1	95.1	96.7	96.7	96.7	100.0	93.4	96.7	95	72.1	42.6
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

4.3.2.2 Pattern of tooth development within dental arches in the Chinese by age

In the Chinese subjects, comparison of tooth development within dental arches and between age groups shows mixed development between maxillary and mandibular arches (**Tables 4.57** and **4.58** for males and females respectively).

The teeth generally developed a little bit earlier in females than in males, as with the Malays. The mandibular permanent teeth developed more quickly than the maxillary permanent teeth, in both genders. Although there was a difference between the right and left sides of the jaws, on average this difference was in one stage rather than in all teeth. This is illustrated in the case of the 8-year-old Chinese males, in which the canine on the right side (13) was at stage E whereas on the left side (23) it was at stage F. Similarly, in the lower jaw, the mineralisation of the canine on the right side (43) was at stage E and left side was at stage F.

In Chinese males, the mandibular central and lateral incisors completed development at 8 years and 10 years respectively, whereas the maxillary central and lateral incisor completed development later at 11 years. In Chinese females, the mandibular central and lateral incisors completed development at 8 years and 9 years respectively, whereas the maxillary central and lateral incisor completed development later at 10 years. The mandibular and maxillary canines, first premolars and second premolars have all completed development at 13 years in males and earlier at 12 years in females. The mandibular and maxillary first molars completed development at 11 years in males and earlier at 10 years in females. The mandibular second molars have completed development at 15 years and 16 years in maxillary second molars in males; similarly, in females, maxillary and mandibular second molars completed development at 15 and 16 years, respectively. In males, the maxillary and mandibular third molars would have completed development of the crown at 11 and 13 years respectively; in females, the maxillary and mandibular third molars would have completed development of the crown at 11 and 12 years respectively. However, the third molar root portion would continue to develop.

Table 4.57: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese males

Age	n																		
Age 5	51	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	100	58.8	54.9	77.1	80.0	49.0	66.7	82.0	82.0	64.7	47.1	78.4	76.5	49.0	62.7	2.0
			Stage	O	C (B-D)	E (D-G)	C (B-D)	C (B-D)	C (C-E)	D (C-D)	D (C-E)	D (C-E)	D (C-D)	C (C-E)	C (B-D)	C (B-D)	E (D-G)	C (B-D)	A
		Man	Stage	O	C (B-D)	E (D-G)	C (B-D)	C (B-D)	D (C-D)	D (D-F)	E (C-G)	E (C-G)	D (D-F)	D (C-D)	C (B-D)	C (B-D)	E (D-G)	C (B-D)	A
			%	100	64.7	58.8	60.8	56.9	66.7	51.0	47.1	47.1	52.0	66.0	58.8	58.8	56.9	66.7	2.0
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 6	60	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	100	71.7	45	57.6	63.8	52.5	63.2	41.4	41.4	66.1	51.7	63.2	57.6	45	72.4	100
			Stage	O	D (C-E)	G (E-G)	D (C-E)	D (C-E)	D (C-E)	D (D-E)	D (D-F)	D (D-G)	D (D-E)	D (C-E)	D (C-E)	D (C-E)	G (E-G)	D (C-E)	O
		Man	Stage	O	D (C-D)	F (E-G)	D (C-E)	D (C-E)	D (C-E)	E (D-G)	F (E-H)	F (E-H)	E (D-G)	D (C-E)	D (C-E)	D (C-E)	F (E-G)	D (C-D)	O
			%	100	65.0	58.3	58.3	71.2	65.0	53.4	44.1	45.8	53.4	66.1	67.8	53.3	58.3	61.7	100
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.57: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese males (continued)

Age	n	Arch																	
Age 7	66	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	3.0	72.7	83.3	69.4	67.7	63.5	54.0	56.2	56.9	54.8	63.5	66.7	69.4	81.5	63.6	4.5
			Stage	B (A-B)	D (C-E)	G (E-G)	D (D-E)	D (D-E)	E (D-F)	E (D-G)	F (D-G)	F (D-G)	E (D-G)	E (D-F)	D (D-E)	D (D-E)	G (E-G)	D (C-E)	A (A-B)
		Man	Stage	B (A-B)	D (C-E)	G (F-G)	D (C-E)	D (D-E)	E (D-F)	F (E-G)	G (F-H)	G (F-H)	F (E-G)	E (D-F)	D (D-E)	D (C-E)	G (F-G)	D (C-E)	A (A-B)
			%	6.1	77.3	83.3	66.7	66.7	61.5	55.4	60.0	59.1	53.8	60.0	65.2	72.3	84.8	84.8	6.1
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Age	n	Arch																	
Age 8	65	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	13.8	50.8	89.2	71.4	72.6	46.9	50.0	47.7	47.7	50.8	46.9	70.3	66.2	83.1	49.2	13.8
			Stage	B (A-C)	E (C-E)	G (F-H)	E (D-F)	E (D-G)	E (D-F)	F (D-G)	F (E-H)	F (E-H)	F (D-G)	F (D-F)	E (D-G)	E (D-F)	G (F-H)	E (D-E)	B (A-C)
		Man	Stage	A (A-B)	D (D-E)	G (G-H)	E (D-F)	E (D-F)	E (D-F)	G (F-H)	H (G-H)	H (G-H)	G (F-H)	F (D-F)	E (D-F)	E (D-F)	G (F-H)	D (D-E)	A (A-B)
			%	12.3	67.7	89.2	66.2	60.9	43.1	61.5	52.3	53.8	60.0	41.5	61.5	60.9	90.8	67.7	10.8
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.57: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese males (continued)

Age	n	Arch																	
Age 9	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	17.1	73.2	73.2	51.2	41.5	63.4	42.5	50.0	48.8	40.0	65.0	42.5	46.3	73.2	68.3	17.1
			Stage	B (A-C)	E (C-F)	G (E-H)	E (D-G)	E (D-G)	F (E-F)	G (E-H)	G (F-H)	G (G-H)	F (E-H)	F (D-F)	E (D-G)	E (D-G)	G (E-H)	E (C-F)	B (A-C)
	41																		
		Man	Stage	B (A-C)	E (D-F)	G (G-H)	E (D-F)	E (D-F)	F (D-F)	H (F-H)	H (G-H)	H (G-H)	G (F-H)	F (D-F)	E (D-F)	E (D-F)	G (G-H)	E (D-F)	B (A-C)
			%	31.7	65.9	78.0	58.5	51.2	53.7	43.9	73.2	73.2	41.5	53.7	56.1	63.4	73.2	70.7	29.3
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 10	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	26.4	58.9	55.6	52.1	48.6	75.3	42.9	50.0	52.1	46.5	74.0	49.3	53.5	58.3	55.6	22.5
			Stage	B (B-E)	E (D-G)	H (G-H)	F (E-H)	F (E-H)	F (E-H)	H (F-H)	G (F-H)	G (F-H)	G (F-H)	F (E-H)	F (E-H)	F (E-H)	G (G-H)	E (D-G)	C (A-E)
	73																		
		Man	Stage	B (A-D)	E (D-G)	H (G-H)	F (D-G)	F (E-H)	F (E-G)	H (G-H)	H (G-H)	H (G-H)	H (G-H)	F (E-G)	F (E-H)	F (D-G)	H (G-H)	E (D-G)	C (A-D)
			%	37.0	63.0	50.7	46.2	58.3	76.5	74.0	93.1	93.2	75.3	74.0	54.8	61.6	53.4	58.9	38.4
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.57: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese males (continued)

Age	n	Arch																	
Age 11	41	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	32.5	48.8	85.4	43.9	56.4	51.2	78.0	87.5	85.4	80.5	46.3	53.8	41.0	87.8	48.8	30.0
			Stage	D (B-C)	G (E-G)	H (G-H)	F (E-H)	G (F-H)	G (F-H)	H (G-H)	H (G-H)	H (G-H)	H (G-H)	G (F-H)	G (F-H)	G (E-H)	H (G-H)	G (E-H)	D (B-D)
		Man	Stage	C (A-D)	G (E-G)	H (G-H)	F (G-H)	G (F-H)	G (F-H)	H (G-H)	H	H	H	G (F-H)	G (F-H)	F (F-H)	H (G-H)	E (E-G)	C (A-D)
			%	42.56	41.5	87.8	68.3	61.0	51.2	92.7	95.1	97.6	95.1	53.7	53.7	63.4	90.2	41.5	42.5
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 12	66	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	57.6	57.6	92.4	55.6	39.4	54.5	89.2	95.4	90.8	89.2	57.6	40.9	53.0	90.8	59.1	53.8
			Stage	D (B-E)	G (E-H)	H (G-H)	G (F-H)	G (F-H)	G (F-H)	H (G-H)	H (G-H)	H (G-H)	H (G-H)	G (F-H)	H (F-H)	G (F-H)	H (G-H)	G (E-H)	D (B-E)
		Man	Stage	D (A-E)	G (E-G)	H (G-H)	G (F-H)	G (F-H)	G (F-H)	H	H	H	H	G (F-H)	G (F-H)	G (F-H)	H (G-H)	G (E-G)	C (B-E)
			%	39.4	60.6	90.8	48.5	51.5	53.8	95.5	98.5	97.0	95.5	54.5	45.5	48.5	90.9	60.6	40.9
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.57: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese males (continued)

	n																		
Age 13	47	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	37.0	70.2	97.9	59.6	78.7	59.6	93.6	93.3	95.7	93.6	51.1	69.6	56.5	100.0	70.2	39.1
			Stage	D (B-F)	G (F-H)	H	H (F-H)	H (G-H)	G (G-H)	H (G-H)	H	H	H (G-H)	H (F-H)	H (G-H)	H (F-H)	H	G (F-H)	D (B-F)
		Man	Stage	D (C-E)	G (G-H)	H	H (F-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	G (F-H)	H	G (F-H)	D (C-E)
			%	40.0	80.9	100	40.4	59.6	63.0	93.6	100	100	93.6	58.7	63.8	46.8	100	83.0	31.1
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

	n																		
Age 14	53	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	44.2	69.8	96.2	73.1	90.6	81.1	98.1	92.5	92.5	94.2	76.9	86.8	75.0	98.1	69.8	41.5
			Stage	E (C-F)	G (F-H)	H	H (G-H)	H (G-H)	H (G-H)	H (G-H)	H	H	H	H (G-H)	H (G-H)	H (G-H)	H	G (F-H)	E (B-F)
		Man	Stage	E (C-F)	G (G-H)	H	H (G-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	H (G-H)	H	G (G-H)	D (C-F)
			%	37.7	75.5	98.1	62.3	84.9	82.4	96.2	94.3	94.3	94.3	84.9	86.8	58.5	96.2	77.4	40.4
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.57: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese males (continued)

Age	n	Arch																	
Age 15	63	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	45.2	52.4	96.8	90.5	92.1	92.1	95.2	98.4	95.2	95.2	90.5	92.1	84.1	96.8	50.8	43.3
			Stage	E (D-H)	G (G-H)	H	H (G-H)	H (G-H)	H (G-H)	H (G-H)	H	H	H	H (G-H)	H (G-H)	H (G-H)	H	G (G-H)	E (D-G)
		Man	Stage	E (D-G)	H (G-H)	H	H (G-H)	H	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	H (G-H)	H	H (G-H)	E (C-G)
			%	52.4	49.2	96.8	79.4	96.8	93.7	98.4	96.8	96.8	96.8	92.1	93.7	85.7	95.2	52.4	49.2
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 16	47	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	38.3	78.7	97.9	89.4	89.4	91.5	93.6	95.7	95.7	93.6	91.5	91.5	89.4	95.7	76.6	21.3
			Stage	G (D-H)	H (G-H)	H	H	H	H	H	H	H	H	H (G-H)	H	H	H	H (G-H)	E (D-G)
		Man	Stage	F (D-G)	H (G-H)	H	H (G-H)	H	H	H	H	H	H	H	H	H (G-H)	H	H (G-H)	E (D-G)
			%	39.1	72.3	95.7	87.2	91.5	93.6	91.5	95.7	95.7	95.7	95.7	87.2	87.2	91.5	78.3	35.6
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.57: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese males (continued)

	n																		
	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	50.0	82.6	97.1	98.6	95.7	97.0	95.6	94.2	97.1	97.1	95.6	97.1	94.1	98.6	82.6	47.1
Age 17	69		Stage	G (E-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (E-H)
		Man	Stage	G (E-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (E-H)
			%	51.5	78.3	98.6	89.9	95.7	97.1	97.1	95.6	97.1	95.6	98.6	94.2	92.8	94.2	79.7	50.0
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.58: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese females

Age	n																			
Age 5	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	100	51.1	46.7	61.9	62.2	55.6	75.0	82.2	82.2	75.0	55.6	62.2	58.1	46.7	51.1	100
			Stage	O	D (B-D)	E (E-G)	C (A-D)	C (B-D)	D (C-E)	D (C-E)	D (D-E)	D (D-E)	D (C-E)	D (C-E)	C (B-D)	C (A-D)	E (D-G)	C (B-D)	O
	45																		
		Man	Stage	O	C (B-D)	E (E-G)	C (B-D)	C (B-E)	D (C-E)	D (C-F)	E (D-G)	E (D-G)	D (C-F)	D (C-E)	C (B-D)	C (B-D)	E (E-G)	C (B-D)	O
			%	100	57.8	48.9	51.1	46.7	57.8	46.3	58.1	58.1	46.3	53.3	48.9	51.1	46.7	57.8	100
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 6	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	100	71.2	60.6	55.4	61.5	60.0	47.6	47.7	48.4	46.8	58.5	60.9	55.4	68.2	75.8	100
			Stage	O	D (C-E)	G (E-G)	D (C-E)	D (C-E)	E (D-F)	E (D-F)	E (D-F)	E (D-F)	E (D-F)	E (D-F)	D (C-E)	D (B-E)	G (E-G)	D (C-E)	O
	66																		
		Man	Stage	O	D (C-D)	G (E-G)	D (C-E)	D (C-E)	D (D-F)	F (D-G)	G (E-H)	G (E-H)	F (D-G)	D (D-F)	D (C-E)	D (B-E)	G (E-G)	D (C-D)	O
			%	100	78.8	56.1	62.1	70.8	52.3	45.9	44.4	44.6	42.9	53.8	65.2	65.2	54.5	74.2	100
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.58: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese females (continued)

Age	n	Arch																	
Age 7	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	10.0	65.0	85.0	48.7	50.0	55.0	50.0	45.0	45.0	50.0	52.5	55.0	53.8	85.0	70.0	7.5
			Stage	A (A-B)	D (C-E)	G (F-G)	D (C-F)	D (C-F)	E (D-F)	E (D-F)	F (D-G)	F (D-G)	E (D-F)	E (D-F)	D (C-F)	D (C-F)	G (F-G)	D (C-E)	B (A-B)
	40																		
		Man	Stage	A (A-B)	D (C-E)	G (E-G)	D (C-F)	D (C-F)	D (D-F)	F (E-H)	G (E-H)	G (E-H)	F (E-H)	E (D-F)	D (C-F)	D (C-F)	G (E-G)	D (C-E)	A
			%	12.5	67.5	87.5	50.0	45.0	48.7	47.5	60.0	60.0	46.2	43.6	47.5	52.5	87.5	65.0	15.0
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 8	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	10.5	61.4	89.5	59.6	50.0	63.2	47.4	60.7	63.2	44.6	64.9	50	57.9	89.5	64.9	8.8
			Stage	C (A-C)	D (D-F)	G (G-H)	F (D-F)	F (E-G)	F (D-G)	F (D-G)	G (E-H)	G (E-H)	F (D-G)	F (D-G)	E (D-F)	E (D-F)	G (G-H)	D (D-F)	C (A-C)
	57																		
		Man	Stage	A (A-C)	D (D-E)	G (G-H)	E (D-F)	E (E-F)	F (E-G)	G (F-H)	H (G-H)	H (G-H)	G (F-H)	F (E-G)	E (D-F)	E (D-F)	G (G-H)	D (D-E)	A (A-C)
			%	15.8	50.9	89.5	73.7	77.2	68.7	73.7	70.2	70.2	73.7	71.4	71.4	71.9	87.7	52.6	14.0
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.58: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese females (continued)

Age	n	Arch																	
Age 9	57	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	31.6	68.4	63.2	51.8	50.9	71.9	50.0	61.4	57.9	49.1	68.4	50.0	44.6	64.9	77.2	28.1
			Stage	B (A-C)	E (D-G)	G (G-H)	F (E-G)	F (E-G)	F (E-H)	G (F-H)	G (F-H)	G (F-H)	G (F-H)	F (E-H)	F (E-G)	F (E-G)	G (G-H)	E (D-G)	B (A-C)
		Man	Stage	B (A-C)	E (D-F)	G (G-H)	E (E-F)	F (E-G)	F (E-G)	H (F-H)	H (G-H)	H (G-H)	H (F-H)	F (E-G)	F (E-G)	E (E-F)	G (G-H)	E (D-F)	B (A-C)
			%	21.1	64.9	57.9	47.4	52.6	66.7	52.6	93.0	91.2	52.6	70.4	50	52.6	61.4	68.4	21.1
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Age	n	Arch																	
Age 10	50	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	24.5	44.0	70.0	40.0	50.0	50.0	63.3	76.0	74.0	66.7	42.9	42.9	48.0	70.0	49.0	22.4
			Stage	D (A-D)	F (D-G)	H (G-H)	F (E-H)	G (F-H)	G (F-H)	H (G-H)	H (G-H)	H (G-H)	H (G-H)	G (E-H)	G (F-H)	F (E-H)	H (G-H)	F (D-G)	C (B-D)
		Man	Stage	B (A-D)	F (D-G)	H (G-H)	F (E-G)	F (E-G)	G (F-H)	H (F-H)	H (G-H)	H (G-H)	H (F-H)	G (F-H)	F (E-G)	F (D-G)	H (G-H)	F (D-G)	C (A-D)
			%	32.0	40.0	76.0	63.3	52.0	59.2	79.6	86.0	86.0	79.6	57.1	46.9	56	72	40.0	34.0
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.58: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese females (continued)

	n																		
	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	31.0	51.7	94.8	53.6	52.6	49.1	94.7	96.6	91.4	96.6	50.0	50.0	55.2	93.1	51.7	35.1
Age 11	58		Stage	D (B-E)	G (D-G)	H	G (E-H)	G (F-H)	G (F-H)	H (G-H)	H (G-H)	H (G-H)	H (G-H)	G (F-H)	G (F-H)	G (E-H)	H (G-H)	G (E-H)	D (B-E)
		Man	Stage	C (A-E)	G (E-G)	H (G-H)	F (E-H)	G (E-H)	G (F-H)	H (G-H)	H	H	H (G-H)	G (F-H)	G (E-H)	G (E-H)	H (G-H)	G (E-G)	C (A-D)
			%	35.1	44.8	94.8	51.7	48.3	60.3	94.8	98.3	98.3	94.8	58.6	51.7	44.8	93.1	43.1	42.9
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	48.3	71.7	91.7	38.3	59.3	55.0	86.4	89.8	90.0	88.1	51.7	54.2	38.3	90.0	71.7	53.3
Age 12	60		Stage	D (B-E)	G (E-H)	H	H (E-H)	H (F-H)	H (F-H)	H (G-H)	H (G-H)	H (G-H)	H	H (F-H)	H (F-H)	H (E-H)	H (G-H)	G (E-H)	D (B-E)
		Man	Stage	D (B-E)	G (E-H)	H (G-H)	H (E-H)	H (E-H)	H (F-H)	H (G-H)	H	H	H (G-H)	H (F-H)	H (E-H)	H (E-H)	H (G-H)	G (E-H)	D (B-E)
			%	55.0	66.7	96.7	40.0	56.7	63.3	95.0	95.0	95.0	95.0	64.4	53.3	38.3	93.3	65.0	50.0
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.58: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese females (continued)

Age	n																		
Age 13	60	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	45.8	71.7	100	61.7	81.4	80.0	100	98.3	100	100	81.7	81.7	61.7	98.3	76.7	39.7
			Stage	D (C-E)	G (F-H)	H	H (F-H)	H (G-H)	H (G-H)	H	H	H	H	H (F-H)	H (G-H)	H (F-H)	H	G (F-H)	D (B-E)
		Man	Stage	D (C-E)	G (F-H)	H (G-H)	G (F-H)	H (F-H)	H (G-H)	H	H	H	H	H (G-H)	H (F-H)	H (F-H)	H	G (F-H)	D (B-E)
			%	43.3	71.7	95.0	51.7	81.7	81.4	98.3	100	100.0	98.3	84.7	75.0	46.7	100	71.7	42.4
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 14	50	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	38.0	64.0	98.0	76.0	84.0	86.0	96.0	98.0	100	96.0	86.0	85.7	78.0	100	68.0	36.0
			Stage	D (D-F)	G (G-H)	H	H (F-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H	H (F-H)	H	G (G-H)	E (C-F)
		Man	Stage	D (C-F)	G (G-H)	H	H (F-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	H (F-H)	H	G (G-H)	E (C-F)
			%	36.2	70.0	100.0	64.0	80.0	94.0	100	100	100	100	93.9	78.0	68.0	100.0	72.0	33.3
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.58: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese females (continued)

Age	n																		
	n	**Max**	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	43.6	51.9	98.7	84.8	94.9	93.7	94.9	100.0	98.7	97.5	96.2	97.5	91.1	97.5	44.3	42.9
			Stage	G (D-G)	H (G-H)	H	H (G-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H	H (G-H)	H	H (G-H)	E (D-G)
Age 15	**79**																		
		Man	**Stage**	E (C-G)	G (G-H)	H	H (F-H)	H	H (G-H)	H	H	H	H	H (G-H)	H	H (G-H)	H	G (G-H)	E (C-G)
			%	50.0	54.4	96.2	82.3	97.5	97.5	100.0	100.0	100.0	100.0	98.7	97.5	82.3	97.5	55.7	50.6
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Age	n																		
	n	**Max**	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	28.0	71.2	98.1	98.1	94.2	98.0	98.1	98.1	98.1	98.1	96.1	94.2	94.2	98.1	76.9	32.0
			Stage	E (D-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H (G-H)	H	H (G-H)	G (D-G)
Age 16	**52**																		
		Man	**Stage**	E (D-G)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	E (D-G)
			%	43.1	63.5	98.1	94.2	98.0	98.1	96.2	98.1	98.1	96.2	98.1	92.2	90.4	94.2	67.3	44.2
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.58: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Chinese females (continued)

	n																		
		Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	42.3	84.9	98.6	95.9	86.3	98.6	98.6	98.6	98.6	97.3	98.6	86.3	97.3	98.6	79.5	45.1
Age 17	73		Stage	G (E-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (D-H)
		Man	Stage	G (D-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (D-H)
			%	35.6	74.0	98.6	93.2	94.5	98.6	98.6	100.0	100.0	97.3	98.6	95.9	89.0	97.3	83.6	38.4
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

4.3.2.3 Pattern of tooth development within dental arches in Indians by age

Comparison of tooth development within dental arches and between age groups in the Indians shows mixed development between maxillary and mandibular arches (**Tables 4.59** and **4.60** for males and females, respectively).

The teeth generally developed a little bit earlier in females than in males. The mandibular permanent teeth developed more quickly than the maxillary permanent teeth, in both genders. Similar to the Malays and Chinese, although some differences were observed between the right and left sides of the jaws, it was in only one stage. As an illustration, in the case of the 10-year-old Indian males, the lateral incisor on the right side (12) was at stage G whereas on the left side (22) it was at stage H. However, in the lower jaw, the mineralisation of the lateral incisors on the right side (42) and on left side (32) was similar at stage H.

With the Indian males, the mandibular central and lateral incisor have completed development at 9 and 10 years and maxillary central and lateral incisors at 10 and 11 years respectively. In Indian females, the mandibular central and lateral incisors completed development at 8 and 9 years respectively; the maxillary central and lateral incisors completed development at 9 and 10 years respectively. In males, the maxillary first premolars completed development at 12 years, whereas maxillary canines and second premolars and mandibular canines, first premolars and second premolars have completed development at 13 years. In females, the mandibular and maxillary canines, first premolars and second premolars completed development at 12 years. The mandibular and maxillary first molars completed development at 9 years in females and 10 years in males respectively. The mandibular and maxillary second molars completed development at 15 years in both genders. In Indian males, the maxillary third molars have completed development crown at 12 year and 13 years in mandibular third molars; in Indian females, the maxillary third molars completed development of the crown at 11 years and 12 years in mandibular third molars. However, the third molar root portion would continue to develop.

Table 4.59: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian males

	n																		
Age 5	28	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	100	46.4	57.1	64.3	67.9	53.6	74.1	70.4	71.4	75.0	53.6	67.9	60.7	60.7	53.6	100
			Stage	O	C	E	C	C	D	D	D	D	D	D	C	C	E	C	O
					(A-D)	(D-G)	(B-D)	(C-D)	(C-E)	(C-D)	(C-F)	(C-F)	(C-D)	(C-E)	(C-D)	(B-D)	(D-G)	(C-D)	
		Man	Stage	O	C	E	C	C	D	E	E	E	E	D	C	C	E	C	O
					(B-D)	(D-G)	(B-D)	(C-D	(C-E)	(D-F)	(D-G)	(D-G)	(D-F)	(C-E)	(C-E)	(B-D)	(D-G)	(B-D)	
			%	100	53.6	50.0	60.7	67.9	57.1	39.3	53.6	53.6	39.3	57.1	71.4	57.1	50.0	46.4	100
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

	n																		
Age 6	48	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	2.1	52.1	43.8	50.0	56.2	50.0	50.0	41.7	41.7	47.9	50.0	54.2	50.0	43.8	56.2	100
			Stage	A	D	G	D	D	D	D	E	E	D	D	C	D	G	D	O
					(C-E)	(E-G)	(B-E)	(C-E)	(C-E)	(D-F)	(D-F)	(D-F)	(D-F)	(C-E)	(C-E)	(C-E)	(E-G)	(C-E)	
		Man	Stage	B	D	F	D	D	D	E	F	F	E	D	D	D	F	D	A
					(C-E)	(E-G)	(C-E)	(C-E)	(C-E)	(D-G)	(E-H)	(E-H)	(D-G)	(C-E)	(C-E)	(C-E)	(E-G)	(C-E)	(B-D)
			%	2.1	60.4	47.9	45.8	47.9	58.3	56.5	42.6	43.5	55.6	58.3	47.9	45.8	45.8	60.4	2.1
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.59: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian males (continued)

Age	n	Arch	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Age 7	44	Max	%	13.6	59.1	81.8	56.8	52.3	61.4	36.4	36.4	38.6	45.5	63.6	55.8	59.1	81.8	61.4	11.4
			Stage	A	D (D-E)	G (F-H)	D (C-F)	D (C-E)	E (D-F)	E (D-G)	F (D-G)	F (D-G)	D (D-G)	E (D-F)	D (C-E)	D (C-F)	G (F-H)	D (D-E)	A
		Man	Stage	A (A-B)	D (C-E)	G (F-H)	D (C-E)	D (C-F)	E (D-G)	F (E-H)	G (F-H)	G (F-H)	G (E-H)	D (D-G)	E (C-F)	D (C-E)	G (F-H)	D (C-E)	A (A-B)
			%	13.6	77.3	81.8	56.8	54.5	58.1	36.6	42.9	44.2	38.1	59.1	52.3	47.7	81.8	79.5	11.4
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Age	n	Arch	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Age 8	40	Max	%	22.5	57.5	87.5	50.0	52.5	47.5	30	45	42.5	37.5	50.0	53.8	52.5	85.0	57.5	27.5
			Stage	B (A-C)	E (D-F)	G (G-H)	E (D-F)	E (D-F)	F (D-F)	F (D-G)	G (E-H)	G (E-H)	F (D-G)	F (D-F)	E (D-F)	E (D-F)	G (F-H)	E (D-F)	B (A-B)
		Man	Stage	B (A-C)	D (D-F)	G (F-H)	E (D-F)	E (D-F)	F (D-G)	G (F-H)	H (G-H)	G (G-H)	G (F-H)	F (D-G)	E (D-F)	E (D-F)	G (F-H)	E (D-F)	A (A-B)
			%	20.0	57.5	77.5	60.0	60.0	50.0	42.5	47.5	55.0	45.0	52.5	57.5	60.0	82.5	55.0	22.5
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular

Table 4.59: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian males (continued)

Age	n	Arch																	
Age 9	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	30.4	70.8	54.2	44.7	39.6	75.0	37.5	58.3	56.2	37.5	75.0	39.6	45.8	54.2	64.6	25.5
	48		Stage	B (A-D)	E (D-F)	G (G-H)	E (E-G)	E (E-G)	F (E-G)	G (E-H)	G (F-H)	G (F-H)	G (F-H)	F (E-G)	E (D-G)	E (D-G)	G (G-H)	E (D-F)	B (A-D)
		Man	Stage	B (A-D)	E (D-F)	G (G-H)	E (D-F)	E (D-G)	F (E-G)	G (F-H)	H (G-H)	H (G-H)	G (F-H)	F (E-G)	E (D-G)	E (D-F)	G (G-H)	E (D-F)	B (A-D)
			%	35.4	68.8	56.2	58.3	53.2	72.9	48.9	76.6	80.9	51.1	75.0	51.1	53.2	52.1	70.8	29.2
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 10	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	26.5	42.3	65.4	43.1	38.5	67.3	46.2	61.5	57.7	46.2	67.3	33.3	42.3	65.4	34.6	26.5
	52		Stage	D (B-D)	E (D-G)	G (G-H)	F (E-G)	G (D-G)	F (E-G)	G (E-H)	H (F-H)	H (F-H)	H (E-H)	F (E-G)	F (D-G)	F (D-G)	H (G-H)	F (D-G)	D (B-D)
		Man	Stage	C (A-D)	E (D-G)	H (G-H)	F (D-G)	F (D-G)	F (E-G)	H (F-H)	H (G-H)	H (G-H)	H (F-H)	F (E-G)	F (D-G)	F (D-G)	H (G-H)	E (D-G)	C (A-D)
			%	38.5	50.0	65.4	53.8	44.2	62.7	82.4	92.3	94.2	80.0	65.4	51.9	55.8	63.5	53.8	34.6
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.59: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian males (continued)

Age	n	Arch																	
Age 11	51	Max	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	29.4	41.2	80.4	36.0	43.8	56.9	66.7	86.3	82.4	62.7	56.9	44.0	35.3	84.3	43.1	34.0
			Stage	C (B-E)	F (D-G)	H (G-H)	G (E-H)	G (E-H)	F (F-H)	H (G-H)	H (G-H)	H (G-H)	H (F-H)	F (E-H)	G (E-H)	G (E-H)	H (G-H)	G (D-G)	C (B-E)
		Man	**Stage**	C (B-E)	F (E-G)	H (G-H)	F (E-H)	F (E-H)	F (F-H)	H (G-H)	H	H	H (G-H)	F (F-H)	F (E-H)	F (E-H)	H (G-H)	F (E-G)	C (B-E)
			%	43.1	43.1	86.3	56.9	43.1	52.0	86.3	100.0	98.0	86.3	56.9	45.1	52.9	88.2	41.2	41.2
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
Age 12	55	Max	**Tooth No.**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	38.2	69.1	94.5	45.5	46.3	49.1	90.9	94.5	94.5	90.9	49.1	42.6	47.3	94.5	67.3	38.2
			Stage	D (B-E)	G (E-H)	H (G-H)	G (F-H)	H (F-H)	G (F-H)	H (G-H)	H (G-H)	H (G-H)	H (G-H)	G (F-H)	H (F-H)	G (F-H)	H (G-H)	G (E-H)	D (B-E)
		Man	**Stage**	C (B-E)	G (E-H)	H (G-H)	G (F-H)	G (F-H)	G (F-H)	H (G-H)	H	H	H (G-H)	G (F-H)	G (F-H)	G (F-H)	H (G-H)	G (E-H)	D (B-E)
			%	43.6	60.0	90.9	41.8	47.3	44.4	92.6	98.1	98.2	92.7	49.1	45.5	41.8	90.9	61.1	36.4
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.59: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian males (continued)

Age	n	Jaw	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Age 13	50	Max	%	54.0	70.0	98.0	72.0	75.0	56.0	92.0	92.0	94.0	96.0	64.0	77.6	66.0	98.0	70.0	50.0
			Stage	D (D-F)	G (F-H)	H	H (F-H)	H (F-H)	H (F-H)	H (G-H)	H	H (G-H)	H (G-H)	H (F-H)	H (F-H)	H (F-H)	H	G (F-H)	D (C-F)
		Man	Stage	D (C-F)	G (F-H)	H	H (F-H)	H (F-H)	H (G-H)	H	H	H	H	H (G-H)	H (F-H)	H (F-H)	H	G (F-H)	D (C-F)
			%	46.0	70.0	98.0	49.0	76.0	57.1	100.0	100.0	100.0	100.0	62.0	70.0	42.0	100.0	68.0	44.9
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Age	n	Jaw	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Age 14	52	Max	%	41.2	55.8	98.1	86.5	96.2	84.6	96.2	94.2	94.2	96.2	84.6	96.2	84.6	98.1	51.6	40.4
			Stage	E (D-G)	G (G-H)	H	H (G-H)	H	H (G-H)	H	H	H	H	H (G-H)	H	H (G-H)	H	G (G-H)	E (C-G)
		Man	Stage	E (D-F)	G (F-H)	H	H (G-H)	H	H (G-H)	H	H	H	H	H (G-H)	H	H (G-H)	H	G (G-H)	E (C-G)
			%	50.0	61.5	96.2	82.7	94.2	90.4	98.1	98.1	98.1	98.1	86.5	94.2	84.6	98.1	61.5	49.0
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.59: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian males (continued)

Age	n	Arch																	
Age 15	61	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	26.7	65.6	96.7	86.9	96.7	93.4	95.1	96.7	95.1	98.4	93.4	95.1	88.5	98.4	67.2	23.0
			Stage	F (D-G)	H (G-H)	H	H (G-H)	H	H (G-H)	H	H	H	H	H (G-H)	H	H (G-H)	H	H (G-H)	F (D-G)
		Man	Stage	E (D-G)	H (G-H)	H	H (G-H)	H	H (G-H)	H	H	H	H	H (G-H)	H	H (G-H)	H	H (G-H)	E (D-G)
			%	36.1	60.7	98.4	86.9	96.7	95.1	98.4	100.0	98.4	100.0	95.1	96.7	86.9	98.4	65.6	37.7
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 16	49	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	35.4	89.8	95.9	100.0	100.0	95.9	95.9	93.9	95.9	98.0	93.9	98.0	98.0	100.0	85.7	33.3
			Stage	G (D-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	F (D-H)
		Man	Stage	G (D-G)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (D-H)
			%	32.7	75.5	98.0	93.9	100.0	98.0	100.0	100.0	100.0	100.0	98.0	98.0	93.9	95.9	77.6	30.6
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.59: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian males (continued)

	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Age 17	53		%	47.2	94.3	100	96.2	98.1	98.1	96.2	96.2	94.3	96.2	98.1	98.1	90.6	100.0	96.2	41.5
			Stage	G (D-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (D-H)
		Man	Stage	G (E-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (D-H)
			%	50	86.8	96.2	98.1	98.1	100	100	98.1	100	100	98.1	98.1	96.2	96.2	88.7	50.9
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.60: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian females

	n																		
Age 5	32	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	100	53.1	40.6	67.7	53.1	56.2	65.6	59.4	62.5	68.8	56.2	53.1	67.7	40.6	53.1	3.1
			Stage	O	D (B-E)	E (D-G)	C (C-E)	C (C-E)	D (C-F)	D (C-E)	D (D-F)	D (D-F)	D (C-E)	D (C-F)	C (C-E)	C (C-E)	E (D-G)	D (B-E)	O
		Man	Stage	O	D (B-D)	E (E-G)	C (B-D)	C (C-D)	D (C-E)	E (D-F)	E (D-G)	E (D-G)	E (D-F)	D (C-E)	C (C-E)	C (A-D)	E (E-G)	D (B-D)	O
			%	100	53.1	46.9	50.0	53.1	59.4	45.2	38.7	38.7	46.9	58.1	56.2	53.1	46.9	46.9	100
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 6	36	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	100.0	66.7	44.4	58.8	71.4	58.3	58.3	61.1	61.1	61.1	50.0	74.3	68.6	44.4	69.4	100.0
			Stage	O	D (C-E)	F (E-G)	D (C-E)	D (C-E)	D (D-F)	D (D-F)	E (D-F)	E (D-F)	E (D-F)	E (D-F)	D (C-E)	D (C-E)	G (E-G)	D (C-E)	O
		Man	Stage	O	D (C-D)	F (F-G)	D (C-D)	D (C-E)	E (C-F)	E (E-F)	F (E-G)	F (E-G)	E (E-F)	E (D-F)	D (C-E)	D (C-D)	F (F-G)	D (C-D)	O
			%	100	72.2	55.6	52.8	75.0	45.7	50.0	50.0	55.6	50.0	50.0	77.8	52.8	55.6	69.4	100
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.60: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian females (continued)

	n																		
Age 7	29	Max	Tooth No.	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	3.4	48.3	85.7	50.0	48.3	58.6	44.8	37.9	41.4	48.3	58.6	53.6	53.6	86.2	44.8	3.4
			Stage	A	E (C-E)	G (F-H)	D (C-E)	D (C-F)	E (D-F)	E (D-G)	F (E-G)	F (E-G)	E (D-G)	E (D-F)	D (D-F)	D (C-E)	G (F-H)	D (C-E)	A
		Man	Stage	A	D (C-E)	G (F-G)	E (C-E)	D (D-E)	E (D-F)	F (E-G)	G (F-H)	G (F-H)	F (E-G)	E (D-F)	D (D-F)	D (C-E)	G (F-G)	D (D-E)	A
			%	6.9	86.2	79.3	44.8	51.7	51.7	48.3	55.2	55.2	48.3	51.7	51.5	48.3	79.3	86.2	10.3
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

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	n																		
Age 8	55	Max	Tooth No.	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	11.1	49.1	90.9	65.5	70.4	60.0	59.6	47.2	50.0	61.5	60.0	65.5	67.3	89.1	49.1	12.7
			Stage	B (A-C)	E (D-F)	G (F-H)	E (D-F)	E (D-G)	F (E-F)	F (E-H)	G (F-H)	G (F-H)	F (E-H)	F (D-G)	E (D-G)	E (D-F)	G (F-H)	E (D-F)	B (A-C)
		Man	Stage	B (A-C)	D (D-E)	G (F-H)	E (D-F)	E (D-F)	F (D-G)	G (F-H)	H (F-H)	H (F-H)	G (F-H)	F (D-G)	E (D-F)	E (D-F)	G (F-H)	E (D-E)	B (A-B)
			%	21.8	56.4	89.1	63.6	65.5	63.0	48.1	53.7	50.0	48.1	70.9	74.5	63.6	90.9	50.9	23.6
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.60: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian females (continued)

Age	n																		
Age 9	49	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	23.4	57.1	51.0	36.7	44.9	69.4	44.9	51.0	49.0	45.8	67.3	52.1	38.8	51.0	53.1	18.8
			Stage	B (A-D)	E (D-G)	H (G-H)	F (D-G)	F (D-H)	F (E-H)	G (E-H)	H (F-H)	H (F-H)	G (E-H)	F (E-H)	F (D-H)	F (D-G)	G (G-H)	E (D-G)	C (A-D)
		Man	Stage	C (A-D)	E (D-G)	H (G-H)	F (D-G)	F (E-H)	F (E-H)	H (F-H)	H (G-H)	H (G-H)	H (F-H)	F (E-H)	F (E-H)	F (D-G)	H (G-H)	E (D-G)	C (A-C)
			%	30.6	55.1	51.0	46.9	51.0	53.1	66.7	85.4	87.5	66.7	55.1	57.1	46.9	53.1	59.2	32.7
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 10	51	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	38.0	41.2	72.5	39.2	46.0	47.1	60.0	68.0	72.0	61.2	56.0	48.0	45.1	66.7	51.0	33.3
			Stage	C (B-D)	E (E-G)	H (G-H)	F (E-H)	G (E-H)	G (F-H)	H (F-H)	H (F-H)	H (F-H)	H (F-H)	G (F-H)	G (E-H)	F (E-H)	H (G-H)	E (E-G)	C (B-D)
		Man	Stage	C (A-D)	E (D-G)	H (G-H)	F (E-H)	F (E-H)	G (F-H)	H (F-H)	H (G-H)	H (G-H)	H (F-H)	G (F-H)	F (E-H)	F (E-H)	H (G-H)	F (D-G)	C (A-D)
			%	51.0	43.1	76.5	54.9	47.1	54.0	80.4	90.2	90.2	80.4	60.8	58.8	51.0	70.6	35.3	47.1
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.60: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian females (continued)

Age	n	Arch																	
Age 11	55	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	36.4	61.8	85.5	43.6	58.2	52.7	83.6	90.7	88.9	83.3	50.9	47.3	40.7	85.5	67.3	38.2
			Stage	D (B-E)	G (E-G)	H (G-H)	G (E-H)	G (F-H)	F (F-H)	H (F-H)	H (G-H)	H (G-H)	H (F-H)	G (E-H)	G (F-H)	G (E-H)	H (G-H)	G (E-G)	D (B-E)
		Man	Stage	D (B-D)	G (D-G)	H (G-H)	G (E-H)	G (F-H)	G (F-H)	H (G-H)	H	H	H (G-H)	H (F-H)	G (E-H)	F (E-H)	H (G-H)	G (D-G)	C (B-D)
			%	32.7	52.7	87.3	47.3	41.8	47.2	92.7	98.2	98.2	90.9	47.3	49.1	40.0	85.5	52.7	32.7
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 12	54	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	50.0	75.9	94.4	50.0	66.7	61.1	96.2	96.2	96.2	92.5	59.3	72.2	53.7	90.7	81.5	53.7
			Stage	D (B-E)	G (F-H)	H (G-H)	H (F-H)	H (F-H)	G (G-H)	H (G-H)	H (G-H)	H	H (G-H)	H (G-H)	H (F-H)	H (F-H)	H (G-H)	G (F-H)	D (B-E)
		Man	Stage	D (B-E)	G (F-H)	H (G-H)	H (F-H)	H (F-H)	H (F-H)	H	H	H	H (G-H)	H (F-H)	H (F-H)	G (F-H)	H	G (F-H)	D (B-E)
			%	52.8	75.9	94.4	42.6	57.4	71.7	98.1	98.1	98.1	94.4	63.0	55.6	40.7	98.1	75.9	46.3
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.60: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian females (continued)

Age	n	Arch																	
Age 13	58	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	39.7	75.9	93.1	65.5	72.4	71.9	94.8	96.6	96.5	94.8	72.4	75.4	69.0	93.1	75.9	40.4
			Stage	E (C-E)	G (G-H)	H (G-H)	H (G-H)	H (G-H)	H G-H)	H	H	H	H	H (G-H)	H (G-H)	G (G-H)	H (G-H)	G (G-H)	D (C-E)
		Man	Stage	D (C-F)	G (F-H)	H	H (F-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	G (F-H)	H	G (F-H)	D (C-F)
			%	44.8	70.7	94.8	53.4	72.4	78.9	96.6	96.6	96.6	96.6	78.9	75.9	51.7	93.1	77.6	43.1
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
Age 14	48	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
			%	41.7	58.3	100.0	87.5	93.8	95.7	100.0	97.9	100.0	100.0	91.3	93.8	85.4	100.0	50.0	51.1
			Stage	E (D-F)	G (G-H)	H	H (G-H)	H (G-H)	H (G-H)	H	H	H	H	H (G-H)	H (G-H)	H (G-H)	H	G (G-H)	E (D-F)
		Man	Stage	E (C-F)	G (G-H)	H	H (G-H)	H (G-H)	H	H	H	H	H	H	H	H (F-H)	H	G (D-G)	E (C-F)
			%	45.8	64.6	97.9	79.2	95.8	100.0	97.9	100.0	100.0	100.0	97.9	93.8	81.2	100.0	66.7	41.7
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.60: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian females (continued)

	n																		
	n	Max	Tooth No.	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	41.2	76.9	98.1	92.3	92.3	98.1	98.1	98.1	100.0	100.0	96.2	92.3	90.4	98.1	76.9	46.2
Age 15	**52**		Stage	G (DG)	H (G-H)	H	H (G-H)	H	H	H	H	H	H	H (G-H)	H	H (G-H)	H	H (G-H)	G (D-G)
		Man	Stage	G (D-G)	H (G-H)	H	H (G-H)	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (C-G)
			%	34.6	65.4	96.2	86.5	94.2	98.1	98.1	98.1	98.1	100.0	96.2	92.3	86.5	96.2	63.5	32.7
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

	n																		
	n	Max	Tooth No.	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
			%	40.8	93.9	100.0	100.0	95.9	100.0	100.0	100.0	100.0	100.0	98.0	95.9	98.0	100.0	89.8	44.9
Age 16	**49**		Stage	G (D-H)	H (G-H)	H	H (G-H)	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (D-H)
		Man	Stage	F (D-G)	H (G-H)	H	H (G-H)	H	H	H	H	H	H	H	H	H (G-H)	H	H (G-H)	E (D-G)
			%	30.6	81.6	98.0	89.8	95.9	98.0	100.0	100.0	100.0	100.0	98.0	95.9	95.9	100.0	77.6	32.7
			Tooth No.	**48**	**47**	**46**	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

Table 4.60: Mineralisation stages according to original Demirjian's classification method of dental arches (Q1, Q2, Q3, Q4) among different age groups (5-17) in Indian females (continued)

	n	Max	Tooth No.	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Age 17	56		%	40.0	89.3	98.2	100.0	98.2	100.0	100.0	100.0	98.2	100.0	100.0	98.2	100.0	98.2	91.1	37.5
			Stage	G (E-H)	H (G-H)	H	H	H	H	H	H	H	H	H	H	H	H	H (G-H)	G (E-H)
		Man	Stage	G (D-H)	H (G-H)	H	H (G-H)	H	H	H	H	H	H	H	H	H (G-H)	H	H (D-G)	G (D-H)
			%	39.3	80.4	98.2	96.4	94.6	100.0	100.0	100.0	100.0	100.0	100.0	96.4	94.6	94.5	80.4	38.2
			Tooth No.	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Note: The data was compiled from cross-tabulation of age versus tooth development. The highest percentage of tooth development of respective age was taken. Max: maxillary. Man: mandibular.

4.3.3 Comparison of the level of tooth development within maxillary and mandibular arches by gender and ethnicity

4.3.3.1 Overall comparison

In order to evaluate the differences in the level of tooth development within dental arches upper right maxilla (Q1), upper left maxilla (Q2), lower left mandibular (Q3) and lower right mandibulat (Q4), a one way repeated measure ANOVA was applied to assess whether there was a difference in tooth development within maxillary and mandibular arches.

Mauchly's test was used to evaluate the sphericity assumption and the result showed that the sphericity assumption for the level of tooth development score was violated (χ^2 =3321.483, p<0.01) therefore the F-value was adjusted by a Greenhouse-Geisser correction.

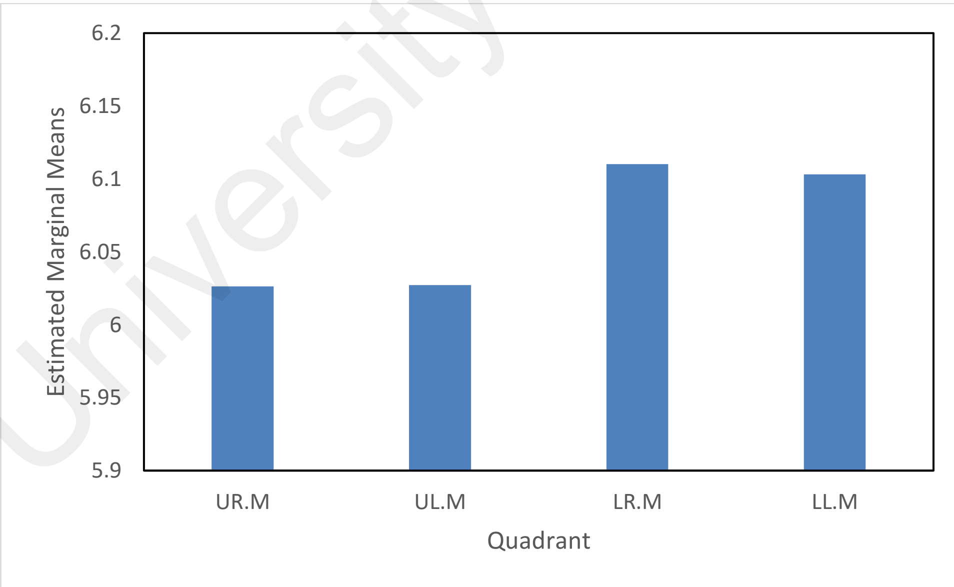
The results of repeated measure ANOVA on tooth development score showed that the differences among the right and left maxillary and mandibular arches were statistically significant ($F_{(2.007,9257.1)}$ =132.785, P<0.05, $\eta 2$=0.028). Therefore to test the related hypothesis, post hoc test (Bonferroni) was applied to compare the mean scores. According to the result (**Table 4.61**) of Bonferroni test it can be concluded that the difference between Q1 and Q2 (p>0.05) and also between Q3 and Q4 (p>0.05) were not statistically significant while the differences between both Q1 and Q2 with Q3 and Q4 were statistically significant (p<0.05).

Table 4.61: Mean difference of tooth development among dental arches using Bonferroni test

(I) PART	(J) PART	Mean Difference (I-J)	SE	P value	95% CI for Difference	
					Lower Bound	Upper Bound
Q1	Q2	-0.001	0.004	1	-0.013	0.011
Q1	Q3	-.084*	0.006	<0.001	-0.1	-0.067
Q1	Q4	-.077*	0.006	<0.001	-0.094	-0.06
Q2	Q3	-.083*	0.006	<0.001	-0.099	-0.066
Q2	Q4	-.076*	0.006	<0.001	-0.093	-0.059
Q3	Q4	0.007	0.004	0.317	-0.003	0.016

Q1: Upper right, Q2: Upper left, Q3: Lower left, Q4: Lower right. *Significant at the 0.05 level.

In general, the level of development in the third and fourth quadrants was more advanced compared to that of first and second quadrants in the total study population (**Figure 4.14**). The upper right or first quadrant was the least developed among the four quadrants.



UR.M: Upper right Maxilla
UR.M: Upper right Mandible
LL.M: Upper left Maxilla
LR.M: Upper left Mandible

Figure 4.14: Mean bar chart of level of tooth development of the general study population in the four dental arches.

4.3.3.2 Gender

In order to evaluate the differences in tooth development score within dental arches (i.e. Q1, Q2, Q3 and Q4) for both genders (female – male) a two-way repeated measure ANOVA was applied to assess whether there was a difference in tooth development score among dental arches for both genders. Mauchly's test was used to evaluate the sphericity assumption and the result showed that the sphericity assumption for attitude was violated (χ^2 =3307.743, p<0.01); therefore the F-value was adjusted by a Greenhouse-Geisser correction.

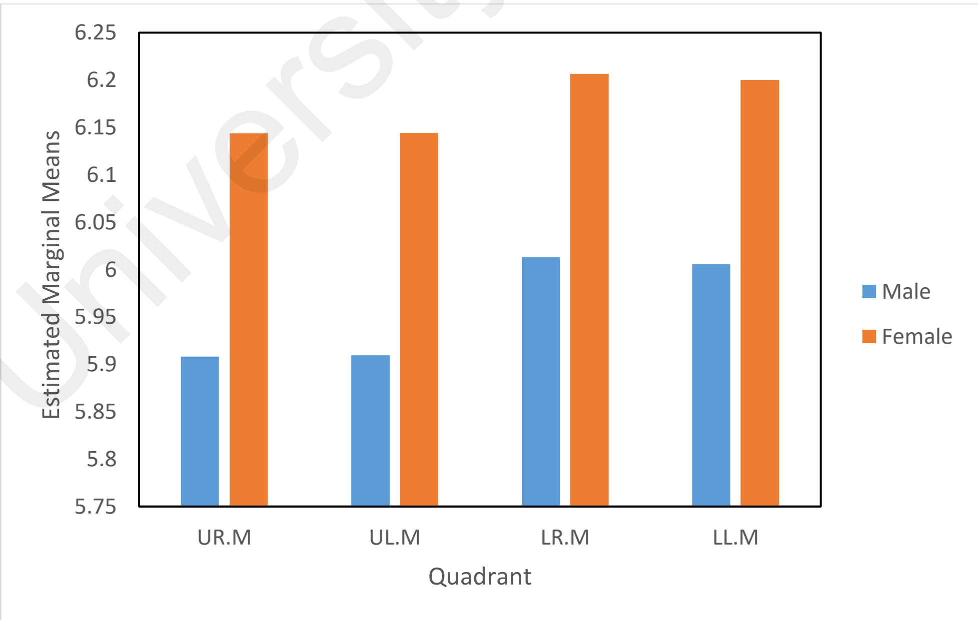
The results of repeated measure ANOVA on tooth development score showed that the interaction between gender and dental arches was statistically significant ($F_{(2.009,9266.741)}$ =8.851 , P<0.05, η2=0.002) when analysed by sex. Therefore, to test the related hypothesis, post hoc test (Bonferroni) was applied to compare the mean scores. It can be concluded that the difference between Q1 and Q2 (p>0.05) and also between Q3 and Q4 (p>0.05) were not statistically significant while the differences between both Q1 and Q2 with Q3 and Q4 were statistically significant (p<0.05) of both gender **(**Bonferroni test; **Table 4.62**).

Table 4.62: Mean difference of tooth development between maxillary and mandibular arches by sex

Sex	(I) Quadrant	(J) Quadrant	Mean Difference (I-J)	SE	P value	95% CI for Difference	
						Lower bound	Upper bound
Male	Q1	Q2	-0.001	0.006	1	-0.018	0.015
	Q1	Q3	-.105*	0.009	0	-0.128	-0.082
	Q1	Q4	-.097*	0.009	0	-0.121	-0.073
	Q2	Q3	-.104*	0.009	0	-0.127	-0.08
	Q2	Q4	-.096*	0.009	0	-0.12	-0.072
	Q3	Q4	0.008	0.005	0.798	-0.006	0.021
Female	Q1	Q2	0	0.006	1	-0.017	0.016
	Q1	Q3	-.063*	0.009	0	-0.086	-0.039
	Q1	Q4	-.056*	0.009	0	-0.08	-0.032
	Q2	Q3	-.062*	0.009	0	-0.085	-0.039
	Q2	Q4	-.056*	0.009	0	-0.08	-0.032
	Q3	Q4	0.006	0.005	1	-0.007	0.02

Q1: Upper right, Q2: Upper left, Q3: Lower left, Q4: Lower right. *Significant at the 0.05 level.

The level of development in the first and second quadrants in females was more advanced compared to males (**Figure 4.15**).



UR.M: Upper right Maxilla
UR.M: Upper right Mandible
LL.M: Upper left Maxilla
LR.M: Upper left Mandible

Figure 4.15: Mean bar chart of level of tooth development segregated by sex in the four quadrants

4.3.3.3 Ethnicity

In order to evaluate the differences in tooth development score within dental arches (i.e. Q1, Q2, Q3 and Q4) for three ethnic groups (Malay, Chinese and Indian) a two-way repeated measure ANOVA was applied to assess whether there were differences in tooth development score among dental arches for three ethnic groups. Mauchly's test was used to evaluate the sphericity assumption and the result showed that the sphericity assumption for attitude was violated (χ^2 =3317.613, p<0.01) therefore the F-value was adjusted by a Greenhouse-Geisser correction.

The results of repeated measure ANOVA on tooth development score showed that the interaction between ethnic groups and dental arches was statistically significant when segregated by ethnicity ($F_{(2.007, 9255.604)}$ =1.496, P=0.200, η2=0.001). Therefore to test the related hypothesis, post hoc test (Bonferroni) was applied to compare the mean scores. Based on the Bonferroni test (**Table 4.63a**) it can be concluded that the difference between Q1 and Q2 (p>0.05) and also between Q3 and Q4 (p>0.05) were not statistically significant while the differences between both Q1 and Q2 with Q3 and Q4 were statistically significant (p<0.05) for all ethnic groups.

Table 4.63a: Mean difference of tooth development between dental arches by ethnicity

Ethnicity	(I) Quadrant	(J) Quadrant	Mean Difference (I-J)	SE	P value	95% CI for difference	
						Lower bound	Upper bound
Malay	1	2	0.002	0.007	1	-0.017	0.02
	1	3	-.097*	0.01	<0.001	-0.123	-0.071
	1	4	-.087*	0.01	<0.001	-0.113	-0.06
	2	3	-.099*	0.01	<0.001	-0.125	-0.073
	2	4	-.088*	0.01	<0.001	-0.115	-0.062
	3	4	0.01	0.006	0.377	-0.004	0.025
Chinese	1	2	-0.002	0.008	1	-0.022	0.019
	1	3	-.081*	0.011	<0.001	-0.11	-0.052
	1	4	-.072*	0.011	<0.001	-0.102	-0.042
	2	3	-.080*	0.011	<0.001	-0.109	-0.051
	2	4	-.070*	0.011	<0.001	-0.1	-0.04
	3	4	0.01	0.006	0.793	-0.007	0.026
Indian	1	2	-0.003	0.009	1	-0.026	0.019
	1	3	-.066*	0.012	<0.001	-0.098	-0.035
	1	4	-.068*	0.012	<0.001	-0.1	-0.035
	2	3	-.063*	0.012	<0.001	-0.095	-0.032
	2	4	-.064*	0.012	<0.001	-0.097	-0.032
	3	4	-0.001	0.007	1	-0.02	0.017

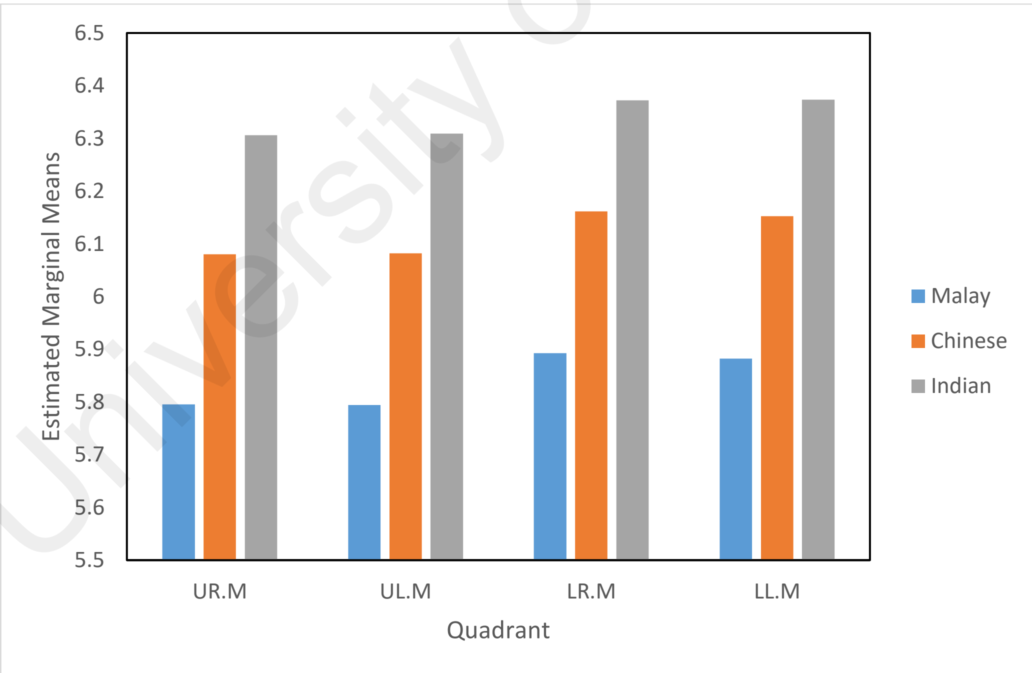
Based on estimated marginal means. *The mean difference is significant at the .05 level. b. Adjustment for multiple comparisons: Bonferroni. 1: Upper right, 2: Upper left, 3: Lower left, 4: Lower right. SE: Standard error.

When comparing the maxillary right quadrant among ethnic groups, the Malays were more delayed in tooth development than Chinese and Indian (**Table 4.63b**). Similarly, the Malays were also delayed in tooth development in the other three quadrants. On the other hand, the Indians were more advanced compared to the Chinese; the Chinese in turn were more advanced than Malays in each of the four quadrants (**Figure 4.16**).

Table 4.63b: Mean differences of tooth development among ethnicity by dental arches

PART	(I) Ethnicity	(J) Ethnicity	Mean Difference (I-J)	SE	P value	95% CI for Difference	
						LB	UB
UR	Malay	Chinese	-0.285*	0.052	<0.001	-0.409	-0.161
	Malay	Indian	-0.510*	0.054	<0.001	-0.64	-0.38
	Chinese	Indian	-0.226*	0.057	<0.001	-0.362	-0.089
UL	Malay	Chinese	-0.288*	0.052	<0.001	-0.412	-0.164
	Malay	Indian	-0.515*	0.054	<0.001	-0.646	-0.385
	Chinese	Indian	-0.227*	0.057	<0.001	-0.364	-0.09
LL	Malay	Chinese	-0.269*	0.049	<0.001	-0.386	-0.152
	Malay	Indian	-0.479*	0.051	<0.001	-0.602	-0.357
	Chinese	Indian	-0.211*	0.054	<0.001	-0.339	-0.082
LR	Malay	Chinese	-0.270*	0.049	<0.001	-0.386	-0.153
	Malay	Indian	-0.491*	0.051	<0.001	-0.614	-0.369
	Chinese	Indian	-0.221*	0.054	<0.001	-0.35	-0.093

UR: Upper right, UL: Upper left, LL: Lower left, LR: Lower right. SE: Standard error. *Significant at the 0.05 level.



UR.M: Upper right Maxilla
UR.M: Upper right Mandible
LL.M: Upper left Maxilla
LR.M: Upper left Mandible

Figure 4.16: Mean bar chart of level of tooth development segregated by ethnicity in the four dental arches.

CHAPTER 5: DISCUSSION

In this study, the applicability of Demirjian's scores for age estimation in Malaysian children aged 5-16 years and 5-18 years were investigated. The dataset in this study was much larger than previous published reports on the Malaysian population, and would be useful in terms of immigration, birth registration and asylum claims because the differences between DA and CA were minimal, indicating a higher accuracy in age estimation, and this was achieved for all the three major ethnic groups in this study.

The discussion was based on three main sections; firstly, the original Demirjian's method (1973), secondly, the modified Demirjian's method (2004), and thirdly, the mineralisation method. The use of ANN in the medical field has grown tremendously in the past decade (Carter, 2007). ANNs have been applied to solve problems such as in the prediction of diagnosis, prognoses, interpretation of diagnostic tests, and decision support (Kaczmarczyk et al., 2011). In a way, ANN could be considered another new modified method for dental age estimation. With each method, comparison among the three major ethnic groups and between males and females were carried out. In addition, for the mineralisation method, comparison among dental arches was also performed.

5.1 Original method (Demirjian 1973)

A total of 3812 samples were used in dental age estimation in the forensics part which is extracted out of 4614 samples. The samples were filtered by excluding those samples with stage X grade (i.e. cannot be graded), samples lacking self-weighted scores (Demirjian, 1973) and samples which were past 13 years of age but were without third molars in the case of the 8-tooth method (Chaillet & Demirjian 2004; John et al., 2012).

In general, when Malaysian children samples were compared with the French-Canadian reference samples, Malaysian children were overestimated or appeared to be advanced in dental maturity as their dental age was overestimated. The finding that Demirjian's method consistently overestimated the age among Malaysian children boys and girls in this study is supported by the paired t-tests results in which the overall mean difference between DA and CA were significant for boys and girls. The discrepancy between the DA and CA in this study for both genders fluctuated with age. Thus, a new approach for DA estimation of Malaysian children was developed based on an adaptation of the reference method.

In this study, when the Malaysian Malay samples were sliced by age groups, the mean difference between DA and CA ranged from +0.01 to +0.89 years in boys and from -0.15 to +0.70 years in girls. This finding was in agreement with a report by Jayaraman et al. (2013), that the difference was statistically significant in some age groups but not in others, for both boys and girls.

The finding based on the 1,236 Malaysian Malays in this study was in agreement with reports by Mani et al. (2008) involving 428 Malay children residing in the state of Kelantan, Asab et al. (2011) involving 905 Malay children; and Nik-Hussein et al. (2011) in 991 Malaysian children residing in the district of Kuala Lumpur, comprising the three main ethnicities which are Malays, Chinese and Indians. Among boys in the present study, the discrepancy in the over-estimation was highest in the 13-year-olds, followed by the 6-year-olds. Erdem et al. (2013) noted that the highest discrepancy occurred in their 5-year-old Turkish boys. On the other hand, among girls in the present study, the discrepancy was highest in the 11-year-olds, followed by the 6-year-olds. In a previous report, the discrepancy was higher among 12-year-old girls (Tunc & Koyuturk, 2008).

In this study, when the 932 Malaysian Chinese subjects were sliced by age groups, the mean difference between DA and CA ranged from +0.13 to +0.9 years in boys and from -0.26 to +0.88 years in girls. There was an under-estimation in the 15-year-old girls; however, in the rest of the age groups the age was overestimated. The mean over-estimation of dental age was 0.47 years in boys and 0.34 years for girls. This finding was in agreement with a report by Davis & Hägg (1994) in 204 samples of Hong Kong Chinese children; Tao et al., (2007) in 828 Shanghai Chinese and Jayaraman et al. (2011) in 182 samples in southern Chinese children- that the difference was statistically significant in 10-year-old boys and 13-year-old girls. The mean over-estimation of dental age of 0.62 years for boys and 0.36 years for girls were also observed by Jayaraman et al.,. On the other hand, an exception was reported by Chen et al., in a population of Sichuan Chinese in which the males were underestimated and females were overestimated (Chen et al., 2010).

In this study, the mean over-estimation of dental age in the Malaysian Indians was 0.56 years for boys and 0.43 years for girls. When the 782 subjects were segregated by age groups, it was found that the mean difference between DA and CA ranged from +0.08 to +1.46 years in boys and from +0.06 to +0.81 years in girls. Other studies also reported over-estimation of age in both Indian boys and girls (Koshy & Tandon, 1998; Prabhakar et al., 2002; Hegde & Sood, 2002; Rai et al; 2007). Another study in an Indian population found that the discrepancy was highest among 13-year-old boys, followed by the 5-year-olds (Kumar & Gopal, 2011).

The over-estimation with the highest discrepancy was attributed to the changes that occurred during the pre-pubertal and pubertal growth phase in children. In a recent meta-analysis involving diverse populations such as Australia, the UK, China, Saudi

Arabia, and many other Caucasian and Asian populations, majority of studies using Demirjian's method as the reference reported an over-estimation of dental maturity that fluctuated with age (Jayaraman et al., 2013). In the meta-analysis, an average 6 months over-estimation of age was found in global population groups (Jayaraman et al., 2013).

The discrepancy indicated that dental growth was not a uniform and a steady process; rather, it is associated with para-pubertal speed fluctuations (Mani et al., 2008). The general over-estimation could be indicative of advanced development of second bicuspids and molars in the French-Canadians. In a more recent study in Turkish children (Erdem et al., 2013), Demirjian's method underestimated the age. The discrepancies in certain age groups may arise due to differences in ethnic origins, culture, environment, diet, secular trend and socio-economic status that influence dental and skeletal maturation (Nik-Hussein et al., 2011). In addition, the highest discrepancies that occurred in girls i.e. 11 years compared to 13 years for boys were consistent with the physiological earlier maturation of other established development influences in the female such as height, sexual maturation and skeletal development compared to the male (Erdem et al., 2013; Demirjian et al., 1985; Loevy & Goldberg, 1999; Hagg & Matson, 1985). In general, majority of studies showed over-estimation in dental maturity, as summarised in Table 5.1. On the other hand, to a lesser extent, several studies reported under-estimation in certain age groups (Patel et al., 2015; Rai et al., 2014; Skanchy et al., 2016).

Therefore, for a more favorable method in DA estimation, predicted Demirjian's scores specific for the Malaysian population were developed for boys and girls respectively. Based on these predicted Demirjian's scores, a new DA conversion table was produced. These gender-specific tables would then be used in DA estimation based on the original Demirjian's method.

5.2 Modified method (Demirjian 2004)

This is also known as the 8-tooth method because it was based on eight teeth (Chaillet & Demirjian, 2004). It was described using ten developmental stages namely 0, 1, and A-H. The original study was based on seven teeth with eight developmental stages A-H (Demirjian et al., 1973). In the current study, eight developmental stages were employed instead of ten for the modified method.

The original 7-tooth Demirjian method, as well as Willems method had been previously tested on Malaysians (Mani et al., 2008; Nik-Hussein et al., 2011; Kumaresan et al., 2014) but not the modified 8-tooth Demirjian method. Since the 8-tooth method has not been applied on any Malaysian population so far, comparison of this part of the study with previously published studies involving Malaysians was not feasible.

When the Malaysian samples in this study were compared against the modified French Canadian reference data, they were generally underestimated, that is, they had delayed dental development. The total mean difference between CA and DA following paired t-tests was statistically significant for both boys and girls.

In recent published reports, particularly from the year 2011, there was a tendency for under-estimation of age using Demirjian's modified data set (**Table 5.1**). In a study in India, a subtotal number of 295 Indians aged 7-16 years were tested using the modified 8-tooth method from a larger pool of 547 subjects aged 7-25 years (Acharya, 2011). The age was underestimated in 73.6% of cases. Another study which sourced the samples from a hospital in south India reported that the modified method underestimated DA by 1.63 years in males, and 1.54 years in females (Sarkar et al., 2013). A similar study on a bigger sample population of 330 males and 330 females aged between 9-20 years old found that the age was underestimated by 1.66 years for boys and 1.55 years for girls (Mohammed et al., 2015). This tendency was also observed in a study that reported under-estimation of the DA by more than two years, in both girls and boys using the modified Demirjian's scores (Khorate et al., 2014). Thus, all the studies generally showed similar scores of under-estimation compared with the current study, and the difference was anywhere from half a year to more than 4 years.

Further scrutiny of each age group in this study revealed that the mean difference between the CA and DA was statistically significant in all the age ranges. The mean difference ranged from +1.55 to +2.34 years in boys and from +2.18 to +4.10 years in girls. The highest discrepancy was observed in boys aged 5 years, followed by the 17-year-olds. With girls, the discrepancy was highest in the 17-year-olds, followed by the 16- to 13-year-olds as well as in 5-year-olds.

A further comparison was performed among those of Indian descent based on the modified method. In this study it was revealed that the mean difference between the CA and DA was statistically significant in all the age brackets in Malaysian Indians when the first line approach of regression analysis was performed. The mean differences ranged from -0.52 to -2.29 years in boys and from -2.02 to -3.73 years in girls. The highest discrepancy was observed in boys aged 6-years, followed by the 5-year-olds. With girls, the discrepancy was highest in the 17-year-olds, followed by the 16- to 15-year-olds as well as in 5-year-olds. The under-estimation in DA that was observed in the Malaysian Indian population using the modified Demirjian's score (Chaillet & Demirjian, 2004) was in line with the findings of other studies on populations of Indian descent (Khorate et al., 2014; Kiran et al., 2015; Mohammed et al., 2015).

The discrepancy in the younger age group may be due to the absence of adjusted weights in the maturity scores as the third molar does not usually develop at 5 years. In fact, a study on 2078 western Chinese children showed that in the 5-year-old children, only 3 out of 68 showed third molar in the crypt stage, whereas the remaining 65 children showed stage 0 (Li et al., 2012). Stage 0 and Stage 1 (also known as crypt stage), were excluded in this study, because at stage 0 there would be no tooth, whereas in Stage 1, the tooth would not have been calcified yet. The crypt stage is when the bone crypt can be observed but there is no dental germ inside. In addition, the weighted score for Stage 0 was only available for third molars in girls, and in second and third molars in boys. On the other hand, the weighted score for Stage 1 was available for third and second molars in girls, and in second, third molars and second premolar in boys (Chaillet & Demirjian 2004). Thus, in this study, the 5-year-old boys, and girls had no third molar score, hence resulting in a wide discrepancy.

The wide discrepancy in the older children who were 13-17 years old in this study had also been reported in previous published studies (Acharya, 2011). It was concluded that including the third molar increased the error rate especially in the older children. The age limit to confirm that the third molar is congenitally missing is after 13 years old. In a study on third molar agenesis in Malaysians, the authors found that 32% of Malaysian Chinese were missing third molars compared to the Malays at 25.5% and Indians at 21.4%. They also found that agenesis of third molar was more prevalent in the mandibular arch compared to the maxillary arch (John et al., 2012). In this study, those subjects who were diagnosed with third molar agenesis after 13 years of age were excluded.

The under-estimation in DA that was observed in the Malaysian population using modified Demirjian’s score (Chaillet & Demirjian, 2004) was in line with the findings of other studies (Acharya, 2011; Sarkar et al., 2013; Mohammed et al., 2015). Apart from genetic factors, other underlying causes such as socio-economic, dietary, and environmental factors may play a role in this variation.

Table 5.1: Comparison of dental age estimation in various populations that employed the original and modified Demirjian methods based on developmental stages of the teeth using radiographs from January 2012-March 2017

Year of publication	Authors	Country/ population	Age range (years)	Method (Demirjian's 7-/8-tooth)	Sample size	Males	Females	Overestimate/ Underestimate	CA – DA (years)	
									Males	Females
2017	Melo et al.	Spain	7-21	7-tooth	2641	1322	1319	Over	0.853	
2016	Azzawi et al.	Egypt	5-13	7-tooth	400	200	200	Over	0.208	0.294
	Alshihri et al.	Saudi	4-16	7-tooth	198	88	110	Over	0.66	0.059
	El Deen	Saudi	4-14	7-tooth	400	222	198	Over	0.279	0.385
	Skanchy et al.	White USA	9-14	7-tooth	199	97	102	Over & under	Under 1.6	Over 0.1
	et al.	Tunisian	2.8-16.5	7-tooth	280	145	135	Over	0.3-1.32	0.26-1.37
	Wolf et al.	German	6-14	7-tooth & others	479	268	211	Over	-0.16	-0.18
	Zhai et al.	Chinese	11-18	8-tooth	1004	392	612	Under	0.47	0.63
	Alshihri et al.	Saudi	4-23	7-tooth	198	88	110	Under	0.02 ±14.5 months	
	Duangto et al.	Thailand	6-15	7-tooth & other	1134	487	647	Over	0.11	0.10
2015	Javadinejad et al.	Iran	3.9-14.5	7-tooth & others	537	284	293	Over	(0.87 ± 1.00 years)	
	Akkaya et al.	Turkish	2.2-15.99	7-tooth & other	799	412	387	Over	0.66	0.52
	Gungor et al.	Turkish	10-18	7-tooth	535	259	276	Over	0.04-0.85	0.02-0.79
	Bijjaragi et al.	Tibetan	8–18	8-tooth	300	150	150	Over (0.04)	-0.09	0.17
	Kiran et al.	India	7-18	8-tooth	250	130	120	Under	0.84	0.83
	Carneiro et al.	Portuguese	6-16	7-tooth	564	260	304	Over	0.07-0.68	-0.01-0.80
	Ginzelová et al.	Czech	3 -18	7-tooth	505	240	265	Over for ≤ 15; Under for ≥ xx	1.783 -2.302	1.170 -2461
	Mohammed et al.	South India	9-20	8-tooth	660	330	330	Under	1.66	1.55
	Mohammed et al.	South India	6-16	7-tooth	660	330	330	Over	0.1 ± 1.63	
	Patel et al.	India	6-16	7-tooth & other	180	90	90	Over & under	Over 6-10 & 15yrs group & under 11-14yrs groups	
	Altunsoy et al.	Western Turkish	7-16	7 Teeth	635	320	315	Over	0.10–0.76	0.28–0.87

Table 5.1: Comparison of dental age estimation in various populations that employed the original and modified Demirjian methods based on developmental stages of the teeth using radiographs from January 2012-March 2017 (continued)

Year of publication	Authors	Country/ population	Age range (years)	Method (Demirjian's 7-/8-tooth)	Sample size	Males	Females	Overestimate/ Underestimate	CA – DA (years)	
									Males	Females
2014	Kumaresan et al.	Mixed (Malay + Chinese + Indian)	5-16	7-tooth	426	179	247	Over	+ 0.54	
	Ambarkova et al.	Macedonia	6-13	1973, 1976 & other	966	481	485	Over	1.06±1.07	1.17±0.987
	Baghdadi	Saudi Arabia	4-14	7-tooth	252	125	127	Over	As whole by about 10 months	
	Celik et al.	Turkey	13-18	7-tooth	932	488	444	Over	-1.02- 1.69	-1.20 - 1.36
	Khorate et al.	India	4-22.1	2004 & Other	500	250	250	Over	2.25	2.32
	Naik et al.	India	7-24	1973	100	53	47	Over ≥16 & less ≤16	-	-
	Rai et al.	India	5-15	1973 & 1941	150	75	75	Group 1, 2 over & group 3 under	-	-
2013	Almeida et al.	Brazil	4.6-16	1973	1854	192	265	Mix	Slow	Earlier
	Baghdadi	Saudi Arabia	4-14	1973 & 2004	452	240	212	Over	8.6 month	7.4 month
	Djukic et al.	Serbia	4-15	1973 & other	686	322	364	Over	0.45	0.42
	Flood et al.	Australia	4.9-14.5	1973 & 1976	143	83	60	Over	-0.18-0.99	0.04-1.38
	Galić et al.	Bosnia and Herzegovina	6-14	1973 & Chaillet et al. 2005	1772	792	980	Over	0.28 ± 0.9	0.09±0.83
	Karataş et al.	Turkey	6-16	1973	832	424	408	Earlier	0.84	0.16
	Sarkar et al.	India	5-24	2004 & other	100	50	50	Under	1.63	1.54
	Shilpa et al.	India	6-15	1973,1976 & 2004	250	126	124	Accuracy only in certain groups	-	-
	Urzel & Bruzek	France	4-15	1973,1976 & 2005 & other	743	357	386	Over	+0.46	+0.45
	Erdem et al.	Turkey	5-13	1973	756	411	345	Over	-0.11 ± 1.04	-0.22 ± 1.1

Table 5.1: Comparison of dental age estimation in various populations that employed the original and modified Demirjian methods based on developmental stages of the teeth using radiographs from January 2012-March 2017 (continued)

Year of publication	Authors	Country/ population	Age range (years)	Method (Demirjian's 7-/8-tooth)	Sample size	Males	Females	Overestimate/ Underestimate	CA – DA (years)	
									Males	Females
2012	Cantekin et al.	Turkey	7-22	1973	1348	622	726	3M advance		
	Feijóo et al.	Spain	2-16	1973	1010	485	525	Over	0.87	0.55
	Grover et al.	India	6-15	1973 & other	215	102	113	Over	0.66	0.56
	Ifesanya & Adeyemi	Nigeria	Up to 16	1973	93	41	52	Over	P=0.009	P=0.051
	Jayaraman et al.	China	2-21	UK data	266	133	133	Under	0.24	
	Kırzıoğlu & Ceyhan	Turkey	7-13	1973 & other	425	212	213	Over	0.52±0.86	0.75±0.90
	Li et al.	China	5-23	1973 & 1976	2078	989	1089	More likely to be under or above 14 or 16	-	-

5.3 New dental scores

Several methods of dental age estimation have been reported in the literature. Despite its population-specific limitations, Demirjian's method has become the benchmark with which other methods were compared (Nik-Hussein et al., 2011). This was partly due to the fact that it enabled a more reliable standardization, had good reproducibility, high intra- and inter-examiner concordance, and had the modified version which used eight teeth instead of seven, to determine the maturity score as a function of age (Chaillet & Demirjian, 2004). However, the use of this modification of Demirjian's method as proposed by Chaillet et al. was not always accurate; for instance when tested in a particular Indian population, it increased the error rate in older individuals (Kumar & Gopal, 2011). In view of these shortcomings, predicted Demirjian's scores specific for the Malaysian children were developed for boys and girls respectively. Based on these predicted Demirjian's scores, new DA conversion tables were produced. These gender-specific tables could be used to estimate age of Malaysian children based on a similar system proposed by Demirjian and co-workers (Demirjian et al., 1973).

However, the discrepancy in the age estimation with the use of Demirjian's dental maturity scores was very wide. In this regard, the use of Demirjian's dental maturity scores for age estimation on global populations has been highly debated (Jayaraman et al., 2016). Against this backdrop of using Demirjian's method across different populations, there was a need for population specific scores, since the French-Canadian dataset showed a tendency to overestimate the age of subjects of other populations by up to more than six months in its original form (Jayaraman et al., 2013) or to underestimate age in its modified form. Demirjian's original dental maturity scores were modified using various statistical methodologies to suit the respective populations. This included logistic regression, multiple linear regression, and Bonferroni corrections of the Demirjian's original maturity scores. In all these cases, the investigators have first-tested Demirjian's method and found that there were differences in dental formation between test and reference groups (Feijóo et al., 2012; Chaillet et al., 2005; Nykänen et al., 1998; Nyström et al., 1988). Similarly, in view of the findings that the age of Malaysian children as a whole was generally overestimated, a new formula for dental age estimation of Malaysian children was developed based on an adaptation of the reference original Demirjian's method (Alghali et al., 2016; Noorazma et al., 2009).

In previously published reports on dental age estimation, regression analysis with a cubic relationship has been used to adjust the CA and Demirjian's scores (Tunc & Koyuturk, 2008). For instance, in a study on Turkish children, Demirjian's scores were analysed by using regression analysis-curve to suit the DA estimation. Based on the modified Demirjian's scores, the difference between CA and DA was not significant, which indicated the accuracy of their adaptation of Demirjian's scores (Erdem et al., 2013). However, in this study, we have not been able to achieve the proximity that was desired; a cubic relationship was initially obtained between CA and Demirjian's scores based on the 7-tooth and 8-tooth method, which was a component of regression analysis. This form of relationship was in agreement with numerous studies employing similar methodologies of analysing the relationship between the two variables (Mohammed et al., 2015). In this study, a cubic relationship was observed to closely describe the relation between CA and DA for the 7-tooth method, with a very high correlation; however, the DA was over-estimated by +0.01 to +0.89 years in boys and from -0.15 to +0.70 years in girls. Similarly, a cubic relationship was observed between CA and DA for the 8-tooth method in this study. A cubic relationship was a regular finding in many studies on DA estimation. However, the DA was under-estimated by more than 1.5 years in this study for the 8-tooth method, which was deemed to be unsatisfactory. Thus, this led to ANN-MLP being employed to predict new Demirjian's scores for the original and modified methods, respectively. The scores were then used to produce the respective NDAs which resulted in a closer estimate of CA.

Several studies have reported on the application of ANN in clinical dentistry to classify dental caries (Devito et al., 2008; Kumar and Gopal, 2011), to plan orthodontic treatment (Xie et al., 2010; Tunc & Koyuturk, 2008), and in the prediction of the size of unerupted canines and premolars (Moghimi et al., 2011; Demirjian et al., 1985). DA estimation has conventionally been analysed using more commonly familiar prediction models such as regression analysis. This conventional approach was acceptable provided the data was linearly separated. Such linear data would be able to be classified easily into two outputs for two classes, with 0 or 1 being the output. However, in the case of dental age estimation, the data was continuous, and could not be conveniently classified into a few groups. ANN would be an approach that was capable of analysing non-linear data (Krogh, 2008). It would be capable of examining the association of certain datasets that could not be analysed using traditional model-based methods. The ANN method produced higher accuracy in DA estimation compared to multiple regression models (Hagg & Matson, 1985; Papantonopoulos, 2014). This was supported by a study conducted in a Czech population on DA estimation (Veleminska et al., 2013). They concluded that ANN was the most accurate multivariate method to adjust the scores compared to simple and linear regression methods.

In this study, ANN-MLP was used to examine the relationship between the input (CA) and output (new maturity score). In an MLP, the input layer was treated using linear combination functions, whereas the hidden layer or layers were treated using sigmoid functions. The hidden layer was further subdivided into units. If there was sufficient data, an MLP consisting of just one hidden layer would learn to estimate almost any function with high accuracy. Thus, MLPs can be used when little is known of the relationship between input (CA) and output (new maturity score). One hidden layer was always sufficient as long as there was sufficient data (Zhang et al., 1998). In this study, one hidden layer was sufficient to describe the relationship between CA and NDA in Malays, Chinese and Indians, both males and females, with the layer being divided into two or three nodes. The application of this method was suitably justified since this study involved over 4000 samples. Thus MLP was utilised in this study to predict a new Demirjian's score, and the NDA which was close to the CA was accurately obtained. The prediction model produced by ANN best represented the CA as a function of Demirjian's scores. The characteristics of an MLP function are signified by two properties. Firstly, the input layer would be treated by using linear combination functions. Secondly, any hidden layer or layers would be treated by using sigmoid functions. In addition, the hidden layer(s) can be subdivided into units. If the data is sufficient, an MLP consisting of just one hidden layer can learn to estimate any function with high accuracy (Nykänen et al., 1998). MLPs are very useful in defining the relationship between two variables which are not fully understood. Such a relationship is observed in DA estimation, which in this case is between CA (input) and the NDA or new maturity score (output).

In this study, in the Malays, the mean difference between the CA and NDA was found at 0.035 ± 0.84 years or about 12 days' difference for boys and 0.048 ± 0.928 years or about 17 days for girls, following data treatment using ANN-MLP, meaning that the CA and NDA were in close agreement. In the Chinese, the mean difference between the CA and NDA was found to be insignificant at -0.048 ± 0.92 years or about 17 days' difference for boys and -0.059 ± 1.11 years or about 21 days for girls. Similarly, a statistically insignificant difference was found in Indians; the mean difference between the CA and NDA was found at 0.033 ± 0.86 years or about 12 days' difference for boys and 0.069 ± 0.98 years or about 25 days for girls. These findings underlined the higher accuracy of the scores post-ANN.

The strength of this study lies in the number of Malaysian juveniles which was greater by far compared to other previous studies on Malaysian subjects. The previous studies either focused on Malays (Mani et al., 2008) and Kelantanese Malay children only (Asab et al., 2011) or the pooled Malaysian population comprising mixed ethnic groups in fewer numbers (Nik-Hussein et al., 2011). In addition, although there was a previous study on DA estimation in the pooled Malaysian population, it included only a few Chinese subjects and employed the original 7-tooth method (Nik-Hussein et al., 2011). It is evident that this study involved a larger sample of Malaysian Chinese children. Additionally, this study also employed both the original and modified methods. The adapted scores of modified Demirjian's data were shown to be accurate in Malaysian Chinese children and adolescents. However, the applicability of these adapted scores for other Chinese groups living in different parts of the world should be tested. Furthermore, this study was the first that used the ANN-MLP approach in DA estimation in the Malaysian population.

It should be clear by now that various researchers have invariably modified the original Demirjian's 7-tooth method by using eight teeth which included the third molar, in the bid to best determine the maturity score as a function of age. The modified method has been employed in several studies to test its accuracy but the result was not always accurate (Bijjaragi et al., 2015). Despite the inaccuracy associated with it, the 8-tooth method was deemed to cater to a specific niche, in that it enabled DA estimation beyond 16 years of age which could not be performed using the original method. The age of 18 years old is significant because it is the age for status of majority i.e. adulthood. Apart from that, it is also the age that is permissible for girls to get married (Jayaraman et al., 2016).

In this study, comparison between the original and modified methods following ANN treatment was performed. It was found that there was no clear indication that the original method was superior to the modified method in terms of accuracy, or vice versa. It has been reported that the original method was more appropriate for DA estimation of children aged 9-13 years old (Bagherpour et al., 2010).

5.4 Pattern of tooth development based on mineralisation

With the original 7-tooth Demirjian's method, it was observed that in Malay samples, the mean ages of attainment of tooth development stages were generally earlier in girls than in boys except in stages G to H of central incisors. However, the development was earlier in males for stages E and G for the first molar tooth. In Chinese samples, the mean ages of attainment of tooth development stages were observed to be generally earlier in girls than in boys except in stage H of central incisors, stages D and H of lateral incisor, stages B & C of first premolar, stage B of second premolar and stage D of second molar in male. In Indian samples, the mean ages of attainment of tooth development stages were observed to be generally earlier in girls than in boys except in stages C and D of second premolar, stage G of first molar, and stage D of second molar in male. This finding was also reported by other investigators (Demirjian et al., 1973) and was consistent with the physiological earlier maturation of other development parameters such as height, sexual maturation and skeletal development in the female (Erdem et al., 2013; Mani et al., 2008; Tao et al., 2007; Davis & Hagg, 1994).

With the modified 8-tooth method of Chaillet & Demirjian, it was observed in Malay and Chinese samples that the mean ages of attainment of tooth development stages were generally earlier in girls than in boys as in the 7-tooth method. However, the third molar mean age of attainment of tooth development stages were observed to be earlier in Malay boys than girls. This finding was in agreement with that reported by Yusof et al. (2015). In the Chinese samples, the third molar mean age of attainment of tooth development stages were observed to be earlier in girls for stages A-C and G-H; however, boys attained earlier tooth development for stages D-F. Qing et al. (2014) reported similar findings, except that stage G was also earlier in their Chinese males. In Indian samples, the mean ages of attainment of tooth development stages were observed to be generally earlier in girls than in boys except in second molar for stages B-G and in third molar for stages D-H (root part), while stages A-C of third molar were earlier in girls. Several other previous published studies reported that the mean ages of attainment of third molar development stages were observed to be generally earlier in Indian boys than in girls for stages D-H (Babburi et al., 2015; Lewis et al., 2015). In addition, Mohammed et al. (2014) reported that Demirjian's modified method underestimated the mean age of third molar of Indian males by 0.8 years and females by 0.5 years and showed that females matured earlier than males in an Indian population.

The inclusion and exclusion criteria for third molar mineralisation should be standardised (Yusof et al., 2015). An example for that would be third molar with horizontal or vertical impaction should be excluded. In addition, the angulation between long axis of third molar and long axis of second molar that is more than 10º should also be excluded. This study does not impose those exclusion criteria employed by Mohd Yusof et al. since we looked into the developmental stage and we believed that this does not have a huge impact on the development of 3 molars.

The Dermijian's original method has been heavily debated as being unsuitable for age estimation, showing a systematic bias and consistent inaccuracy (Carneiro et al., 2015; Jayaraman et al., 2016; Cardoso et al., 2016). Some researchers have used the developing 16 teeth on the left maxilla and mandible and both third molars on the right, or all third molars were staged following Demirjian's classification (Alsaffar et al., 2017; Birchler et al., 2015). In fact, there are other methods of age estimation using third molars, a case in point is the Cameriere's method, which was recently used to determine the legal adult age of 18 years old, by using the third molar maturity index or accuracy of the third molar index (Franklin et al., 2016; Zelic et al., 2016).

The age of legal importance is different from one country to another. Age of legal importance may refer to the minimum age of criminal responsibilities, employment age, legal age to consent for sexual relationship and age for marriage for both males and females (Jayaraman et al., 2016).

The pattern of analysis tooth development by age in this study was similar a study titled "the London Atlas of Human Tooth Development and Eruption" based on the right side of the jaw that was produced by AlQahtani et al. (2010). A Turkish study also produced a dental chart according to tooth development and eruption for the Turkish population based on Al-Qahtani et al.'s report (Karaday et al., 2014), which was generally consistent with the pattern of tooth development from this study. For example, in the 10-year-old Malay and Chinese boys in this study, all 8 teeth were similar in development compared to the Turkish population, but the Indian boys at the same age were more advanced in some stages compared to the Turkish boys.

Another way of looking at tooth development and mineralisation is by analysing each individual tooth independently. In this study, the pattern of tooth development between the maxillary and mandibular arches in Malaysian juveniles was examined based on the individual tooth. In a study by Cavric et al. (2016), they descriptively evaluated the time of mineralisation of all teeth from the left sides of the maxilla and mandible. The average age of each tooth at each stage of development showed that the Malaysian girls were generally faster than boys especially in the first and second quadrants, in agreement with the findings by Cavric et al. (2016) and Karaday et al. (2014). Karaday et al. (2014) showed that third molar mineralisation was similar in both their Turkish males and females, except for difference in one stage in one jaw in three age groups. In this study, remarkably, the third molar mineralisation was also similar between the boys and girls, except for differences by one stage in three age groups in Malays, three age groups in Chinese and three age groups in Indians. There were reports of differences by two stages (Sisman et al., 2007).

To further illustrate the point that the difference in tooth development generally occurred by one stage, in this study, the Malay male completed development earlier in mandibular incisors at 9 years, whereas in Spanish males, the incisors completed development at 10 years; the canine and two premolars completed development at 13 years in this study, at the same age as the Spanish males in Feijóo's study; in this study, the first and second molars of mandibular and maxillary teeth completed development at 10 and 15 years respectively, compared to 11 years and 14 years in studies by Feijóo et al. (2012) and Karaday et al. (2014). In this study, the maxillary central and lateral incisors completed development earlier at 10 years and 11 years respectively, compared to Spanish males at 11 years for both incisors. The canine and first premolar at 13 years and 14 years for the second premolar in this study, compared to 13 years in Feijóo et al. (2012). Similar patterns of differences in tooth development can be seen in the Malay girls, as well as Chinese and Indian girls and boys.

Comparison of level of tooth development within dental arches showed that the third and fourth quadrants was more advanced compared to that of first and second quadrants in the total study population, in agreement with that reported by Karaday et al. (2014) and Nizam et al. (2003). The difference between Q1 and Q2 ($p>0.05$) and also between Q3 and Q4 ($p>0.05$) were not statistically significant while the differences between both Q1 and Q2 with Q3 and Q4 were statistically significant ($p<0.05$) for both genders and all ethnic groups. The level of tooth development in the Indians was more advanced compared to the Chinese, and in turn the Chinese were more advanced than

Malays in each of the four quadrants. Emergence of teeth in Malaysian ethnic groups has been reported. Earlier emergence of teeth was shown in the Chinese (Hong Kong) and the Punjabi (Chandigarh) compared to Malays. In contrast, Malays showed earlier emergence compared to the Thais in Central Thailand (Hussin et al., 2007).

There are advantages in using the mineralisation system to estimate the age of an individual: it is simple, specialised training to recognize specific stages is not necessary and specialised equipment is not needed except for the basic DPT setup (Blenkin & Taylor., 2012). There were times when comparison between age groups of this study with other published studies could not be performed meaningfully, due to the differences in definition of age range. For example, Cavric et al. (2016) defined the age range for a 6-year-old as 6 – 6.9 which was similar to this study and could thus be compared correspondingly, but Karaday et al. (2014) defined it as 5.50 – 6.49. In addition, there have been comparatively fewer studies that evaluated the maxillary dentition together with the mandibular set (Feijóo et al., 2012). This approach of evaluating the maxilla and mandible simultaneously contrasted with the two methods employed earlier in this thesis, namely Demirjian's original and modified methods, which solely relied on the lower left jaw which is part of the mandible. Viewing the mandible is easier because it is clearer, with less superimposition of the roots and distortion of the teeth, compared to the maxilla.

The Malaysian population comprises mixture of cultures and inter-racial marriages. In the classification of subjects by ethnicity, the exact ethnic origin in these cases of inter-racial marriages would not be able to be traced, and this is a limitation of this study.

CHAPTER 6: CONCLUSION

6.1 Summary

Forensic age determination of juveniles (≤ 18.0 years of age) is typically performed using the developing dentition. Researchers including Demirijan et al. defined eight stages of dental development, based on tooth mineralisation. Demirjian's DA estimation method has become one of the most widely accepted methods by forensic scientists. The method is simple, reliable, and reproducible.

Despite the reported simplicity and accuracy of Demirjian's method, it has been found to overestimate chronological age. Thus, Demirjian's original seven-tooth method was modified by using eight teeth which included the third molar. Third molars exhibited wide variations in rate of development. Although the modified method has been employed in several studies, the result was not always accurate. However, inclusion of third molars can provide additional information for assessment beyond 16 years old, i.e. 18 years old, which could not be performed using the original 7-tooth method. The age of 18 years old is significant for various reasons.

Maturity scores have been used to calculate the predictive interval of Demirjian's dental maturity percentile curves. Several authors have replacing the scoring of Demirjian's method by using polynomial regression or multiple linear regressions successfully. This study attempted the same; however, it could not achieve the closeness in agreement satisfactorily.

This predicament was circumvented by using the ANN-MLP method to examine the relationship between the input (chronological age) and output (new maturity score). The ANN model produced scores with higher accuracy in DA estimation compared to multiple regression models.

This study found that the average age of each tooth at each stage of development showed that Malaysian girls were generally faster than boys especially in the first and second quadrants, in agreement with previously published reports. Comparison of level of tooth development within dental arches showed that the third and fourth quadrants were more advanced compared to that of first and second quadrants in the total study population. The difference between Q1 and Q2 ($p>0.05$) and also between Q3 and Q4 ($p>0.05$) were not statistically significant while the differences between both Q1 and Q2 with Q3 and Q4 were statistically significant ($p<0.05$) of both gender and all ethnic groups. The level of tooth development in the Indians was more advanced compared to the Chinese, and in turn the Chinese were more advanced than Malays in each of the four quadrants.

6.2 Conclusion

The original Demirjian's method overestimated the age of Malaysian children. On the other hand, the modified Demirjian's method underestimated the age of these children. Thus, a novel gender- and ethnic-specific age prediction model for Malaysian children based on Demirjian's 7-tooth and 8-tooth method were developed and validated to allow for more accurate age estimation. This large scale ethnic-specific data can be used to estimate the age of Malaysian children in both clinical and forensic applications in the future.

6.3 Recommendations and suggestions for future research

The applicability of these adapted scores of both 7-tooth and 8-tooth methods for other gender and ethnic groups living in different parts of the world should be tested.

Results from other prediction methods should be compared by using the ANN prediction model/method for more accuracy and more applicability.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

List of ISI publications

1. Safar Sumit Bunyarit, Jayakumar Jayaraman, Murali K. Naidu, Rozaida Poh Yuen Ying, Mahmoud Danaee, Phrabhakaran Nambiar. Modified method of dental age estimation of Malay juveniles. Legal Medicine 2017; 28: 45-53.
   (ISI-cited publication)

2. Safar Sumit Bunyarit, Jayakumar Jayaraman, Murali K. Naidu, Rozaida Poh Yuen Ying, Phrabhakaran Nambiar. Dental age estimation of Malaysian Chinese children and adolescents using artificial multilayer perceptron neural network.
   (Manuscript in preparation)

Oral presentations

1. Safar Sumit Bunyarit, Dental Age Assessment (DAA Part 1). Seminar presentation at Faculty of Dentistry, Universiti Kebangsaan Malaysia. Jalan Raja Muda Abdul Aziz, 50300 Kuala Lumpur, Malaysia (11^{th} October 2013).

2. Safar Sumit Bunyarit, Three-Minute Thesis Competition 2016 Faculty Level. Faculty of Dentistry, University of Malaya, 50603 Kuala Lumpur, Malaysia (7^{th} – 18^{th} March 2016).