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Relationship between dental age, skeletal maturity and chronological age in young orthodontic patients.

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June 2014

Abstract

Objectives: The aim of this study was to find out in what extend the dental age and skeletal maturity relate with the chronological age, in a sample of 50 subjects in the range 7 – 16 years old, from the Northern part of Norway

Subjects and methods: The subjects were all patients who had received/were undergoing orthodontic treatment at the Public Dental Service Competence Centre of Northern Norway (TkNN). The sample consisted of 25 males and 25 females, from 7-16 years in age. The subjects were selected to represent 5 different age groups, and each group consisted of 5 boys and 5 girls. The inclusion criteria were age between 7 and 16 at the time the OPG and lateral cephalogram were taken, and presence of the 7 left side mandibular teeth. Dental age was assessed on panoramic radiographs by using Demirjian and Goldstein radiographic analysis. This method is based on ratings of radiographs of the seven left side teeth of the mandible. Skeletal maturity was assessed by using the Cervical Vertebral Maturation method, which is a method for assessing adolescent growth stage and for predicting the start of the pubertal growth spurt in orthodontic patients.

Results: There was a strong correlation between all measured variables. The correlation coefficients between chronological age and cervical stage were 0,871 for girls and 0,902 for boys, between chronological age and dental age 0,900 for both girls and boys, and between dental age and cervical stage 0,846 and 0,900 for girls and boys respectively. Chronological age was significantly higher than dental age among both boys (P=0,020) and girls (P=0,002) and the difference was more marked in girl. In average, girls reached their pubertal growth spurt (CS 3) at a younger age than boys. Dental age in the end of the pubertal growth spurt (CS 4) varied considerably more among girls (range 10,1-15,2 years) as compared with boys (range 13.1-14.7 years).

Conclusion: In this sample, the chronological age was generally higher than the dental age. There were strong correlations between chronological age, dental age and the skeletal maturity. The usefulness of the high correlations found in our study may be limited in clinical orthodontics.

Introduction

Timing is a key word in orthodontics, especially considering the appropriate time for initiation of different treatment procedures in the growing patient. Optimally, treatment should be started at the onset of the pubertal growth spurt.(1, 2) One of the reasons is that treatment in patients with skeletal imbalances can take benefit during this rapid growth period. A treatment initiated at the wrong time, will increase the risk for an unfortunate outcome. For example, the result seems to be successful at the end of the treatment, but it might relapse after some time, because the treatment was ended before the patients' pubertal growth spurt occurred(3).

The chronological age is often a good indication, but not per se. There are large individual differences between girls and boys concerning when the patient reaches puberty. Girls often begin the process of puberty at a lower age than boys (4). This means that girls often will enter the pubertal growth spurt at a younger age than boys. To utilize the growth spurt, this suggests that girls demand treatment at an earlier point of time than the boys.

Body height (5-7), skeletal maturation of the hand and wrist (8-11), menarche and voice changes (12, 13), are all examples of biological indicators of skeletal maturity (1). These indicators mainly refer to somatic changes at puberty, while the maxilla and mandible follow a pattern of growth that is intermediate between neural and somatic growth. According to *Laura Mitchell* in *An Introduction to Orthodontics*, the mandible follows the somatic growth curve more closely than the maxilla, which has a more neural growth pattern(14).

Age determination is not only essential to orthodontic treatment, but also in in forensic medicine, social and legal settings, and pediatric endocrinology. In these cases dental radiographs, such as an OPG, can be helpful to get the patient's age more accurate. The best-known method based on dental maturation to assess dental age among children and adolescents, was made by Demirjan, Goldsten and Tanner, in 1973 (15). This method has been modified several times since then. By describing the normal variation in dental development, in dentistry and orthodontics, it makes it possible to tell if an individual is advanced or delayed in his/her dental maturation. As compared to somatic growth, the calcification rate of the teeth is controlled more by genes than by environment factors, which gives a lower variability (16, 17). Studies done by Anderson et al, 1975 has shown that tooth development is independent of hormonal and nutritional factors(18). Other studies have shown that age determination assessing dental maturity correlates to the chronological age in a greater extent than other methods of measuring the development, such as skeletal maturation, height and weight(19, 20).

To assess skeletal maturation, hand-wrist radiograph is one of the most widely used methods. However, this method has some drawbacks regarding the variability in somatic growth and bone maturation, which is influenced by environmental factors – such as malnutrition or abnormal endocrinology and underlying endocrinology pathology (21). A study assessing individual skeletal maturity with three different methods (hand-wrist method, middle phalanx of third finger method (MP3) and cervical vertebrae maturation method) to assess individual skeletal maturity showed that hand-wrist radiographs precision in identifying the pubertal growth spurt was lower than for the cervical vertebra maturation method (CVM method) (22). In addition, hand-wrist radiographs will require extra radiation of the patient, since it has to be taken additional to a lateral cephalogram, which is routinely used for orthodontic diagnosis and treatment planning. By using a single lateral cephalogram, where only the second through the fourth cervical vertebrae are visible, the skeletal maturity can be assessed(1). The cervical vertebras are divided into 6 stages, and these stages can predict the start of the pubertal growth spurt including the peak of mandibular growth. The clinical application of the CVM assessment in orthodontic treatment is used as a maturational index for evaluating the time of pubertal growth spurt and for timing the onset of treatment accordingly (23, 24).

As already mentioned, the most frequently used extraoral projection in orthodontics is lateral cephalometric view, in addition to panoramic imaging. All cephalometric radiographs are made with a cephalostat that helps maintain a constant relationship among the skull, the film, and the x-ray beam. Skeletal, dental, and soft tissue anatomic landmarks delineate lines, planes, angles, and distances that are used to generate measurements and to classify patient craniofacial morphologic features (25).

Panoramic imaging is a technique for producing a single tomographic image of the facial structures that includes both the maxillary and mandibular dental arches and their supporting structures(25). Digital panoramic imaging has become the latest technology of presenting radiographic details to the viewer for clinical diagnosis. Application of digital panoramic images is burgeoning due to its benefits such as fast communication of images, small storage space required and minimum contamination to the environment. Moreover, digital panoramic technique have also further advances in dental imaging technology due to its advantages of providing optimal diagnostic images with low radiation dose when compared to the conventional technique(26). The panoramic radiographs are used in orthodontic practice to provide information about axial inclinations, ectopic eruption, unerupted and congenitally missing teeth, stage of eruption, and surrounding tissues of the teeth(27).

According to present studies, the effective dose of a conventional lateral cephalogram is 5.03 microsieverts (µSv) without radiation protection. If a thyroid shield is applied, the dose is reduced with 1.73 µSv. A conventional hand-wrist radiograph has an effective dose of 0.16 µSv(28). According to European guidelines on radiation protection in dental radiology, the effective dose of a panoramic radiography is 3,85 – 30 µSv. Even at the high end of the range, the doses are equivalent to a few days of natural background radiation. For comparison, a flight from Brussels to Athens at a distance of approximately 2100 km (1304 miles), has an effective dose of 10 µSv (29).

Mohit Gupta et al. showed a close correlation between chronological age, dental age and skeletal age among monozygotic and dizygotic twins (30). Vinod Kumar et al. compared the relationship between dental age, bone age and chronological age in underweight children. They found that dental age and bone age were delayed compared to chronological age in both males and females, and that the correlation between chronological age, dental age and bone age were all positive in males (31).

Aim of the study

The aim of the present study was to find out in what extend the dental age and skeletal maturity relate with the chronological age, in a sample of 50 subjects in the range 7 – 16 years old, from the Northern part of Norway.

Subjects and methods

Subjects

To assess the skeletal maturity, dental age and chronological age, we selected a sample of 50 subjects (25 males and 25 females), from 7 to 16 years in age, who had an OPG and a cephalogram taken because of orthodontic treatment at the Public Dental Service Competence Centre of Northern Norway (TkNN). The subjects were selected to represent 5 different-age groups: 7-8,9 years, 9-10,9 yrs, 11-12,9 yrs, 13-14,9 yrs, 15-16,9 yrs. Each group consisted of 5 boys and 5 girls, 50 subjects in total. The patient's chronological age was obtained from patients' database, by subtracting the birthdates from the date the radiographs were taken and converted into years with one decimal (Opus, version 7.0, Opus Systemer AS, Norway).

Methods

Dental age

The Dental age was assessed on panoramic radiograph by using Demirjian and Goldstein radiographic analysis (32). The method is based on ratings of radiographs of the seven left side teeth of the mandible, which have been shown to be representative of all the teeth of the mandible. This method consists of identifying eight stages of calcification for each tooth, ranging from the calcification of the tip of a cusp to the closure of the apex (Figure 1). The stages were labelled 0 for no calcification and A to H for the 8 calcification stages. 8 stages of calcification for each tooth were identified and described and each one was allocated a score. The sum of these scores for an individual provided an estimate of dental maturity on a scale measuring from 0 to 100. Scores and percentile standards are given separately for boys and girls for the age range 3,5-16 years. The overall maturity score was then converted to a dental age by using available tables (32) (Table 1). In this study, Finnish norms for the dental maturity scores were used (33) (Table 2). Examples of dental age assessments are given in Figures 2-3.

Skeletal age

Cervical vertebral maturation (CVM) is a method to evaluate skeletal maturity on lateral cephalograms, which has proven to be useful for assessing adolescent growth stage and especially for predicting the start of the pubertal growth spurt in orthodontic patients. (34-38). The method is based on developmental changes in the morphology of the three cervical vertebrae (C2, C3, C4), which can be seen on lateral cephalograms and are evaluated by visual inspection. According to the CVM, the variables that were analyzed were presence or absence of a concavity at the lower border of the body of C2, C3, and C4; and the shape of the body of C3 and C4. Four basic shapes was considered: trapezoid (the superior border is tapered from posterior to anterior), rectangular horizontal (the heights of the posterior and anterior borders are equal; the superior and inferior borders are longer than the anterior and posterior borders); squared (the posterior, superior, anterior, and inferior borders are equal); and rectangular vertical (the posterior and anterior borders are longer than the superior and inferior borders) (39)(Figure 4). After the morphologic characteristics of the vertebral bodies of C2, C3 and C4 were analyzed, the subjects were placed in cervical stage 1-6 according to the CVM method (1)(Figure 4).

Cervical stage 1 (figure 5): The lower borders of all the three vertebrae (C2-C4) are flat. The bodies of both C3 and C4 are trapezoid in shape (the superior border of the vertebral body is tapered from posterior to anterior). The pubertal growth spurt (peak in mandibular growth) will start on average 2 years after this stage.
Cervical stage 2 (figure 6): A concavity is present at the lower border of C2 .The bodies of both C3 and C4 are still trapezoid in shape. The peak in mandibular growth will occur on average 1 year after this stage.
Cervical stage 3 (figure 7): Concavities at the lower borders of both C2 and C3 are present. The bodies of C3 and C4 may be either trapezoid or rectangular horizontal in shape. The peak in mandibular growth will occur during the year after this stage.
Cervical stage 4 (figure 8): Concavities at the lower borders of C2, C3, and C4 now are present. The bodies of both C3 and C4 are rectangular horizontal in shape. The peak in

mandibular growth has occurred within 1 or 2 years before this stage.

Cervical stage 5 (figure 9): The concavities at the lower borders of C2, C3, and C4 still are present. At least one of the bodies of C3 and C4 is squared in shape. If not squared, the body of the other cervical vertebra still is rectangular horizontal. The peak in mandibular growth has ended at least 1 year before this stage.

Cervical stage 6 (figure 10): The concavities at the lower borders of C2, C3, and C4 still are evident. At least one of the bodies of C3 and C4 is rectangular vertical in shape. If not rectangular vertical, the body of the other cervical vertebra is squared. The peak in mandibular growth has ended at least 2 years before this stage.

Cervical stages 1-3 represent pre-pubertal or pubertal (CS3) growth stages, while CS 4-6 represent post-pubertal growth stages. Clinical examples of cervical stages 1-6 are shown in Figures 5-10.

In the Demirjian method for dental age estimation the observers (E. L. and T.T.) were calibrated by an oral radiologist (N.L.B.). In the CVM assessment they were calibrated by an orthodontist (R.M.). Both calibrators were experienced in these methods. The observers were not calibrated against each other. The assessments were done in a dark room, using an Olorin i3-2120 computer screen (contrast 1000:1, resolution 1280x1024). The panoramic and cephalometric radiographs assessed with the software Dimaxis were taken with Promax Dimax 3 digital (Planmeca, Helsinki, Finland), and the radiographs assessed with the software Digora® Optime were taken with Cranex® D (Soredex, Milwaukee, USA).

Statistical analyses

To compare correlations between dental age, skeletal maturation stage and the subjects' chronological age two different tests were used: Spearman's rank correlation coefficient for non-parametric correlation of categorical variables) and the T-test for analysing the difference between chronological age and dental age (continuous variables). In the T-test, a P-value below 0,05 shows that there is significant difference.

Reliability of measurements

All panoramic radiographs and cephalometric radiographs were assessed by two independent examiners and the assessments were repeated after two weeks. Inter- and intra-examiner agreements were calculated for both dental age and cervical stage by using the Cohen's kappa coefficient of agreement. (40)Both girls and boys separated, and girls and boys in total. Interpretation of the Kappa values was made according to guidelines by Landis & Koch (41).

Results

Inter- and intra examiner reliability of the assessments.

The kappa values for inter-examiner agreement in the assessment of dental age were 0.7907 in the 1^{st} evaluation and 0.8699 in the repeated evaluation. The intra-examiner agreements between first and second measurement of dental age were k= 0.9244 (1^{st} examiner) and k=0.8963 (2^{nd} examiner). Correspondingly the inter-examiner 1^{st} and 2^{nd} agreements in CVM assessments were k=0.941 and 0.9765, and for intra-examiner agreement k=0.9626 (1^{st} examiner) and 0.8802 (2^{nd} examiner). The results of the reliability tests indicated substantial to almost perfect (reliability) agreement according to guidelines by Landis and Koch(41).

The results showed that there was a strong correlation between all measured variables. The correlation coefficients between chronological age and cervical stage were 0,871 for girls and 0,902 for boys, between chronological age and dental age 0,900 for both girls and boys, and between dental age and cervical stage 0,846 and 0,900 for girls and boys respectively. All the correlation coefficients were higher than 0,8, and classified as a very strong correlation, meaning they were strongly related. Chronological age and dental age differed significantly from each other among both boys (P=0,020) and girls (P=0,002). The difference was more marked in girls, meaning the girls in the sample had a bigger difference between chronological age and dental age than the boys.

Four of the girls and 8 of the boys were classified in CS 3 (Table 3). This gave an average chronological age of 10,7 years for the girls and 11,8 years for the boys who were in their pubertal growth spurt. Nine of the girls and 6 of the boys were classified in CS 4, giving an average chronological age of 12,8 years for the girls and 13,8 years for the boys, during the stage when the pubertal growth spurt was over and the growth was slowing down.

Chronological age in relation to dental age (Figure 11)

In younger patients, the plot showing the difference between chronological age and dental age was closer to the mean, indicating a tendency that chronological age and dental age were closer to each other as compared with the older age groups, who had more scattering indicating more diversity between dental and chronological age. Most of the subjects had a positive difference between chronological age and dental age = chronological age was higher than the dental age. Only a few subjects had a negative difference - a chronological age below the dental age.

Chronological age in relation to cervical stage (CVM stage) (Figure 12)

In average, girls reached their pubertal growth spurt (CS 3) at a younger age than boys. According to the linear trend lines, deviations from the means increased with age. The first girl reaching CS 3 had a chronological age of 9,3 years, while the first boy reached the same stage at the age of 10,4 years – almost a year later. The variation in the chronological age of boys in CS 3 was 4,7 years (range 10,4 – 15,1) and 3,8 years (range 9,3 – 13,1) in girls.

Cervical stage (CVM stage) in relation to dental age (Figure 13)

Among girls in CS 4 the dental age ranged from 10,1-15,2 years, which indicated a large variation of dental age at the time when their growth was starting to slow down. The variation in dental age in boys was considerably lower, ranging from 13,1-14,7 years in the same cervical stage. Looking at the whole sample, one subject (a girl) with CS 3 had a dental age of 8,5 years, whereas the last one (a boy) was in the same stage as his dental age was 14,7 years.

Discussion

Relationship between chronological age and dental age

In our sample, the chronological age was somewhat higher than the dental age, with some exceptions. Although the chronological age and dental age were highly correlated, individual variability in dental age was found and must be considered also in clinical orthodontics. This study also showed that the difference to dental age increased with age, especially in the girls, and was biggest after puberty. Our findings support several earlier studies reporting similar variations between chronological age and dental development. Ifesanya and Adeyemi found that there was a significant difference between the chronological and dental age among boys (p=0,009), but not in girls (p=0,051)(42). Bagherian and Sadeghi showed that the mean age difference between dental age and chronological age among Iranian Children, when determined using the Demirjian method based on French-Canadian children, was 0,15 years for boys and 0,21 years for girls. They stated that Iranian children were more advanced in dental maturation compared to French-Canadian children and that these differences were statistically significant (p=0,001)(43). Hence, tooth development seems to vary between populations(44). Corresponding differences have been shown among several ethnic groups worldwide. Even between cities in the same country, variations have been detected (44).

Correlation between cervical stage and chronological age

The high correlation in this study found between chronological age and CVM might indicate, in general, that the chronological age could be suitable to measuring skeletal maturity. However, the large individual variation found in the age of starting and slowing down of the pubertal growth spurt (CS 3 and 4) must be born in mind. Alkhal et al. found a bit lower correlation between CVM and chronological age in a Chinese sample of 400 subjects people than in our present study (0,749 for boys, and 0,776 for girls)(45). It is difficult to know exactly why there is a difference. A possible explanation could be different age distribution between the samples. In the study by Alkhal et al., the female subjects were between 10 and 15 years, and male subjects between 12 and 17 years old, while our sample included also subjects from 7 to 10 years old. This might explain the higher correlations in our sample, since individual variation in growth and development, including the skeletal age, increases with age, as seen also in this study. Ethnicity could also have an impact; in Chinese populations growth patterns could be somewhat different compared to people from Northern Norway. Our study was better in line with Baidas, who found a correlation of 0,864 between chronologic age and cervical vertebrae maturation for the sexes combined in adolescents from Saudi Arabia(46).

Despite of high correlations, it is known from earlier studies, that chronological age is considered a poor indicator for estimating the degree of skeletal maturity. This is due to significant growth variations among individual children of the same chronological age (12, 47, 48). Therefore, especially in class II-patients, it is important to estimate individually when the growth spurt will occur to be able to utilize the patient’s growth in the treatment. There seems to be a wide consensus suggesting that optimal timing for functional/orthopedic treatment of Class II malocclusion is during the pubertal growth spurt (23, 49, 50). Functional or orthopedic therapy of Class II malocclusion just after the onset of the pubertal growth spurt is recommended to favor maximum treatment effect and to reduce duration of treatment and the retention time after treatment. Too early initiated treatment will increase treatment time and, without retention, it may lead to relapse of the treatment outcome, because the growth pattern of severe Class II malocclusion tends to strive constantly to reassert itself, especially when pubertal growth spurt occurs during the post retention period (23). However, particularly in severe skeletal Class II patients, the evaluation of optimal timing of the orthodontic treatment is recommended to be done individually on each patient (49).

The growth spurt occurs between cervical stages 3 and 4 (1). In our sample the pubertal growth spurt occurred earlier in girls than in boys. A study done by Mellion et al. showed that the pubertal growth spurt in mandibular length occurred in girls at the age 9,5 years, and in boys at the age 11,9 years in a sample of subjects from Bolton-Brush Growth Study Center in Cleveland, Ohio, using the hand-wrist method(2). Compared to Mellion et al, the girls in our sample from Northern Norway reached the pubertal growth spurt 1,2 years later, while the average age of the boys in our study was pretty close to the average by Mellion et al. The difference in the validity regarding the CVM method and hand-wrist method has although to be taken into account. A weakness with the Cervical Vertebral Maturation (CVM) Method-is that it cannot be determined whether the patient is in the beginning or end of a stage. The time between each stage is approximately 1,5 years according to Baccetti et al. (1), unlike dental age which is given with an accuracy of months. Because of this, the cervical stage is not as accurate measurement as the dental age.

Correlation between dental age and cervical stage

This study was in line with e.g. the study by Valizadeh et al. on a sample of 400 females from India. In spite of the fact that Valizadeh et al. differentiated between the various teeth, they found the correlation coefficients between cervical vertebral maturation and dental calcifcation significant to be high for all the teeth (r=0,702-0,75), except for the permanent incisors and first molar. (0,3 and 0,4, respectively). Therefore they concluded that skeletal maturity could be predicted by using the calcification stages (51). Sachan et al. evaluated the relationship between cervical vertebral maturation and the calcification of just the canine. They concluded that because the correlations between skeletal maturation indicator and canine calcification were good for both male (r=0,645) and female (r=0,891) subjects, canine calcification stages could therefore be used for assessing bone maturation (52). However, regardless of the substantial correlations reported in that study, the clinical significance may be limited on an individual level.

One of the girls in this study's sample was classified in cervical stage 3, while her dental age was 8,5 years. This means that she at that point had not got her permanent canines, premolars and second molars yet. Because of this, it would have been too early to start treatment with e.g. fixed appliances. The treatment plan and treatment method are affected not only by the patient's growth, but also by the dental development. If a skeletal effect is needed to achieve a sufficient treatment outcome, it is important that the clinician do not rely entirely on the patient's dental age, but also takes the skeletal stage into consideration. An opposite example was a boy in our sample who had full permanent dentition (dental age 14,7 years) while he was in cervical stage 3, meaning he still had a lot of growth left.

A drawback with the Demirjian method in dental age estimation when applied to a Norwegian population was that it is based on data from French-Canadian children. It has been shown that tooth development has variations among populations (44).These differences exist between ethnic groups worldwide, and there is even a tendency towards differences between children within a country (44). But according to Nykänen R et al. who tested the validity of the Demirjian method when applied to Norwegian children, the dental age standards appeared to be applicable for groups of children from a Norwegian population. This conclusion was made although they found that the Norwegian children in general were slightly more advanced in dental maturity as compared to the French-Canadian reference sample (53).

Limitations of the present study

The small sample size was a clear limitation of this study, and the results cannot be generalized or considered as representative of children in the north of Norway. Another limitation with the present study was that the subject's age and presence of the 7 left side mandibular teeth were the only inclusion criteria. Ethnicity, history of congenital or systemic disorders was not taken into account. The observers did never get to meet the subjects in person, neither did they look into the subjects' health records. Therefore, the results only show trends in a demographically rather homogeneous population in Northern Norway.

Conclusion

- In this sample, the chronological age was generally higher than the dental age.
- High correlations were found between chronological age, dental age and skeletal maturity.
- The usefulness of the high correlations found in our study may be limited in clinical orthodontics due to the high individual variation. Therefore, if growth is needed to achieve the treatment goals, evaluation of the growth stage is suggested be done individually for each patient.

Acknowledgements

Rita Myrlund, specialist in orthodontics.

Erik Carlos Halland Haro, radiographer.

Josefine Halbig, specialist in pediatric dentistry.

Elisabeth Camling, executive at TkNN.

References

1. Baccetti T, Franchi L, McNamara JA. The Cervical Vertebral Maturation (CVM) Method for the Assessment of Optimal Treatment Timing in Dentofacial Orthopedics. Seminars in Orthodontics. 2005;11(3):119-29.
2. Mellion ZJ, Behrents RG, Johnston Jr LE. The pattern of facial skeletal growth and its relationship to various common indexes of maturation. Am J Orthod Dentofacial Orthop. 2013;143(6):845-54.
3. Nanda RS, Nanda SK. Considerations of dentofacial growth in long-term retention and stability: is active retention needed? Am J Orthod Dentofacial Orthop. 1992;101(4):297-302.
4. Tanner JM, Whitehouse RH, Marshall WA, BS C. Prediction of adult height, bone age, and occurrence of menarche, at age 4 to 16 with allowance for midparental height. Arch Dis Child. 1975;50:14-26.
5. Nanda RS. The rates of growth of several facial components measured from serial cephalometric roentgenograms. Am J Orthod Dentofacial Orthop. 1955;41:658-73.
6. Björk A. Variations in the Growth Pattern of the Human Mandible: Longitudinal Radiographic Study by the Implant Method. J Dent Res. 1963;42:400-11.
7. Hunter CJ. The Correlation Of Facial Growth With Body Height And Skeletal Maturation At Adolescence. The Angle Orthodontist. 1966;36(1):44-54.
8. Greulich WW, Pyle SI. Radiographic Atlas of Skeletal Development of the Hand and Wrist

: Stanford University Press; 2 edition; 1959.
9. Björk A, Helm S. Prediction of the age of maximum puberal growth in body height. Angle Orthod. 1967;37:134-43.
10. Tofani M. Mandibular growth at puberty. Am J Orthod Dentofacial Orthop. 1972;62(2):176-94.
11. Hägg U, Taranger J. Menarche and voice changes as indicators of the pubertal growth spurt. Acta Odontol Scand. 1980;38(3):179-86.
12. Tanner JM. Growth at Adolescence 2nd ed1962.
13. Hägg U, Taranger J. Skeletal stages of the hand and wrist as indicators of the pubertal growth spurt. Acta Odontol Scand. 1980;38:178-200.
14. Mitchell L. An Introduction to Orthodontics: Oxford University Press; 2007.
15. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol. 1973;45(2):211-27.
16. Moorrees CF, Fanning EA, Hunt EE Jr. Age Variation of Formation Stages for Ten Permanent Teeth. J Dent Res. 1963;42:1490-502.
17. Nolla C. The development of permanent teeth: J Dent Child 1960.
18. Anderson DL, Thompson GW, Popovich F. Interrelationships of dental maturity, skeletal maturity, height and weight from age 4 to 14 years. Growth. 1975;39(4):453-62.
19. Liliequist B, Lundberg M. Skeletal and tooth development. A methodologic investigation. Acta Radiol Diagn (Stockh). 1971;11(2):97-112.
20. Demirjian A, Buschang PH, Tanguay R, Patterson DK. Interrelationships among measures of somatic, skeletal, dental, and sexual maturity. . Am J Orthod Dentofacial Orthop. 1985;88(5):433-8.
21. Hawley NL, Rousham EK, Johnson W, Norris SA, Pettifor JM, Cameron N. Determinants of relative skeletal maturity in South African children. Bone. 2012;50(1):259-64.
22. Pasciuti E, Franchi L, Baccetti T, Milani S, Farronato G. Comparison of three methods to assess individual skeletal maturity. Journal of Orofacial Orthopedics. 2013;74(5):397-408.
23. Baccetti T, Franchi L, Toth LR, McNamara JA Jr. Treatment timing for Twin-block therapy. Am J Orthod Dentofacial Orthop. 2000;118(2):159-70.
24. Baccetti T, L F. Maximizing esthetic and functional changes in Class II treatment by means of appropriate treatment timing, in Mc- Namara JA Jr, Kelly KA (eds): New Frontiers in Facial Esthetics.

Craniofacial Growth Series, Vol 38. Ann Arbor, MI, Center for Human Growth and Development, University of Michigan. 2001:237-51.
25. White SC, Pharoah MJ. Oral Radiology: Principles and Interpretation. 6 ed: Mosby Elsevier; 2008.
26. Sabarudin A, Tiau YJ. Image quality assessment in panoramic dental radiography: a comparative study between conventional and digital systems. Quant Imaging Med Surg. 2013;3(1):43-8.
27. Okşayan R, Aktan AM, Sökücü O, Haştar E, Ciftci ME. Does the panoramic radiography have the power to identify the gonial angle in orthodontics? ScientificWorldJournal 2012;2012.
28. Patcas R, Signorelli L, Peltomäki T, Schätzle M. Is the use of the cervical vertebrae maturation method justified to determine skeletal age? A comparison of radiation dose of two strategies for skeletal age estimation. Eur J Orthod. 2013;35(5):604-9.
29. European guidelines on radiation protection in dental radiology. 2004.
30. Grupta M, Divyashree R, Abhilash PR, Bijle MNA, Murali KV. Correlation between Chronological Age, Dental Age and Skeletal Age among Monozygoyic and Dizygotic Twins. J Int Oral Health. 2013;5(1):16-22.
31. Kumar V, Venkataraghavan K, Krishnan R, Patil K, Munoli K, Karthik S. The relationship between dental age, bone age and chronological age in underweight children. J Pharm Bioallied Sci. 2013;5(1):73-9.
32. Demirjian A, Goldstein H. New systems for dental maturity based on seven and four teeth. Ann Hum Biol. 1976;3(5):411-21.
33. Kataja M, Nyström M, Aine L. Dental maturity standards in southern Finland. Proc Finn Dent Soc. 1989;85(3):187-97.
34. Lamparski DG. Skeletal Age Assessment Utilizing Cervical Vertebrae. Am J Orthod Dentofacial Orthop. 1975;67(4):458-59.
35. O'Reilly MT, Yanniello GJ. Mandibular growth changes and maturation of cervical vertebrae--a longitudinal cephalometric study. Angle Orthod. 1988;58(2):179-84.
36. Hassel B, Farman AG. Skeletal maturation evaluation using cervical vertebrae. Am J Orthod Dentofacial Orthop. 1995;107(6):58-66.
37. García-Fernandez P, Torre H, Flores L, Rea J. The Cervical Vertebrae as Maturational Indicators. J Clin Orthod 1998;32(4):221-25.
38. Franchi L, Baccetti T, McNamara JA. Mandibular growth as related to cervical vertebral maturation and body height. Am J Orthod Dentofacial Orthop. 2000;118(3):335-40.
39. Tanner JM, Whitehouse RH, Cameron N, Marshall WA, Healy MJR, Goldstein H. Assessment of Skeletal Maturity and Prediction of Adult Height (TW2 Method): Academic Pr; 2 Sub edition; 1983.
40. Fleiss JL, Cohen J. The Equivalence of Weighted Kappa and the Intraclass Correlation Coefficient as Measures of Reliability. Educational and Psychological Measurement. 1973;33:613.
41. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159-74.
42. Ifesanya JU, Adeymi AT. Accuracy of age estimation using Demirjian method among Nigerian children. Afr J Med Med Sci. 2012;41(3):297-300.
43. Bagherian A, Sadeghi M. Assessment of dental maturity of children aged 3,5 to 13,5 years using the Demirjian method in an Iranian population. J Oral Sci. 2011;53(1):37-42.
44. Nyström M, Ranta R, Kataja M, Silvola H. Comparisons of dental maturity between the rural community of Kuhmo in northeastern Finland and the city of Helsinki. Community Dent Oral Epidemiol. 1988;16(4):215-7.
45. Alkhal HA, Wong RW, AB. R. Correlation between chronological age, cervical vertebral maturation and Fishman's skeletal maturity indicators in southern Chinese. Angle Orthod. 2008;78(4):591-6.
46. Baidas L. Correlation between cervical vertebrae morphology and chronological age in Saudi adolescents. King Saud University Journal of Dental Sciences. 2011;3(1):21-6.

47. Hägg U, Pancherz H. Dentofacial orthopaedics in relation to chronological age, growth period and skeletal development. An analysis of 72 male patients with Class II division 1 malocclusion treated with the Herbst appliance. Eur J Orthod. 1988;10(1):169-76.
48. Simmons K, Greulich WW. Menarcheal age and the height, weight, and skeletal age of girls age 7 to 17 years. The Journal of Pediatrics. 1943;22(5):518-48.
49. O'Brien K, Wright J, Conboy F, Appelbe P, Davies L, Connolly I, et al. Early treatment for Class II Division 1 malocclusion with the Twin-block: a multi-center, randomized, controlled trial. Am J Orthod Dentofacial Orthop. 2009;135(5):573-9.
50. Tulloch JF, Proffit WR, Phillips C. Outcomes in a 2-phase randomized clinical trial of early Class II treatment. Am J Orthod Dentofacial Orthop. 2004;125(6):657-67.
51. Valizadeh S, Eil N, Ehsani S, Bakhshandeh H. Correlation Between Dental and Cervical Vertebral Maturation in Iranian Females. Iranian Journal of Radiology. 2012;10(1):1-7.
52. Sachan K, Sharma VP, Tandon P. A correlative study of dental age and skeletal maturation. Indian Journal of Dental Research. 2011;22 (6):882.
53. Nykänen R, Espeland L, Kvaal SI, Krogstad O. Validity of the Demirjian method for dental age estimation when applied to Norwegian children. Acta Odontol Scand. 1998;56(4):238-44.

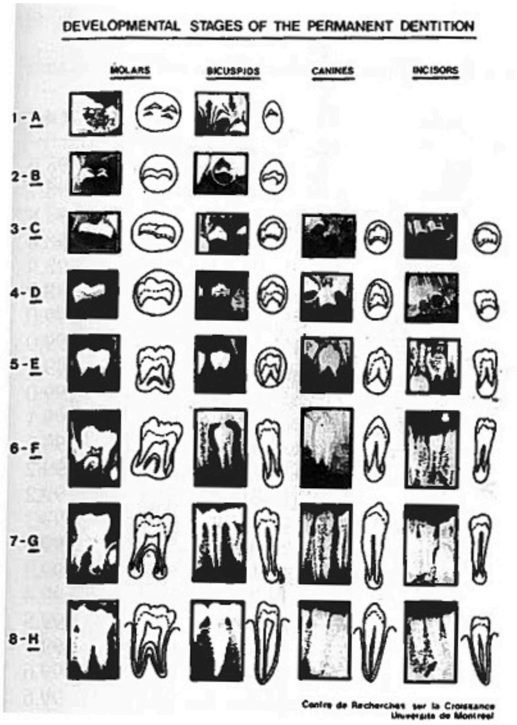

Figure 1: Assessment of dental maturity with the radiographic method by Demirijan and Goldstein.

Figure 2: Clinical example of Demirjian and Goldstein's assessment of dental maturity.
A cropped panoramic radiograph of an 8-year-old girl, assessed according to the instructions by Demirjian and Goldstein; The formation stages of the seven left mandibular teeth are (from M2) D, G, E, E, E, G, H. The corresponding scores are 9.0+12.5+11.1+12.6+7.3+11.2+15.8, and the summed score is 79.5. This gives her the dental age 8.1 years

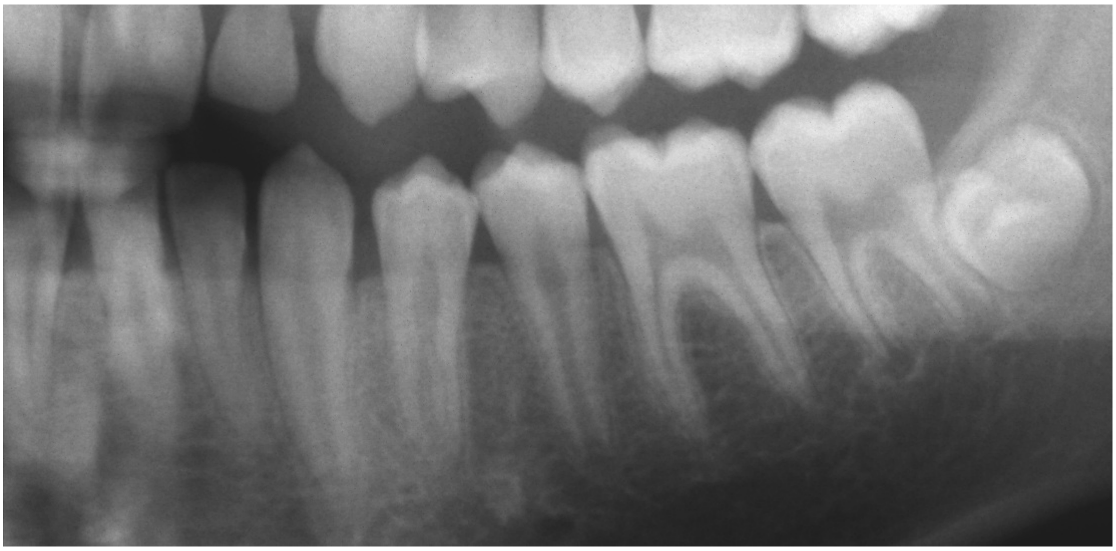

Figure 3: Another clinical example. A cropped panoramic radiograph of a 13.4-year.old boy. The formation stages of the seven left mandibular teeth are (from M2) G,H,G,G,G,H,H. The summed score gives him the dental age 13.2.

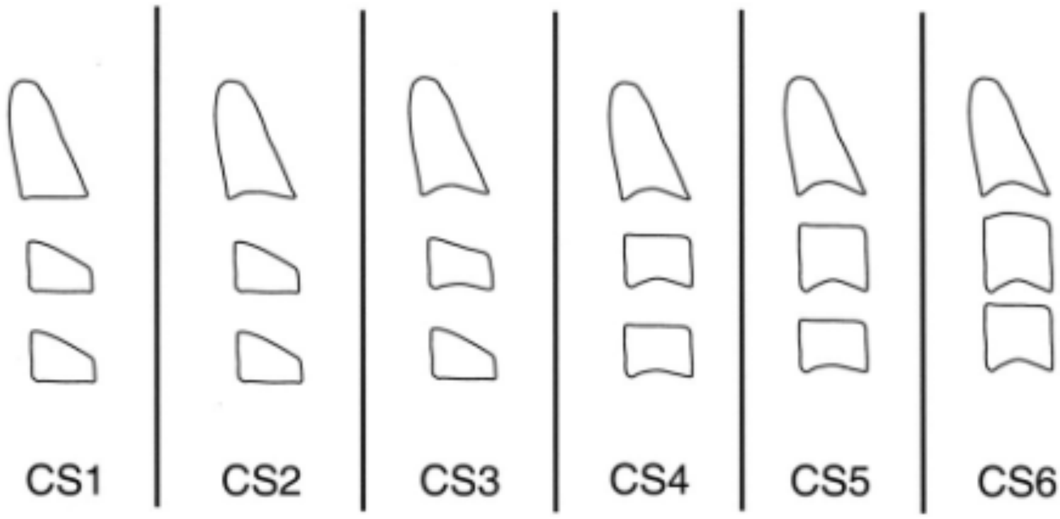

Figure 4: The cervical vertebral maturation method according to the modified method by Baccetti et al. (1).

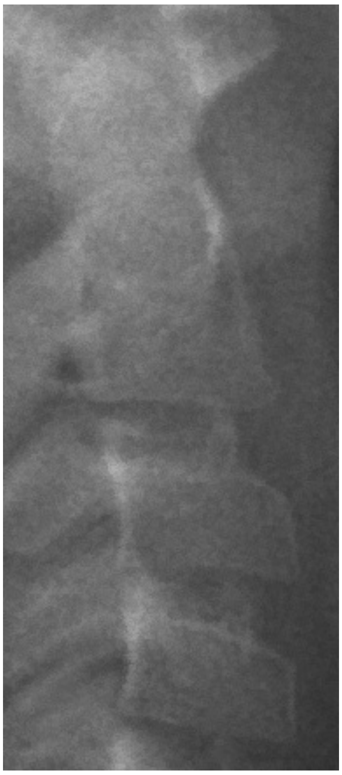

Figure 5: CS1

Figure 6: CS2

Figure 7: CS3

Figure 8: CS4

Figure 9: CS5

Figure 10: CS6

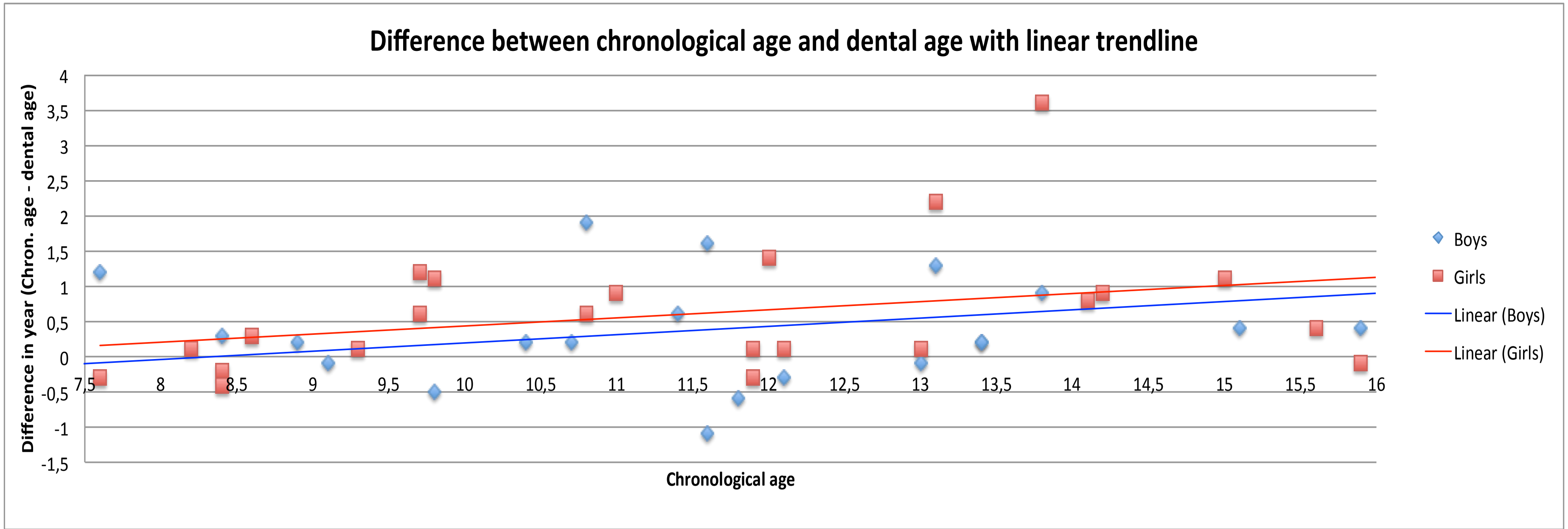

Figure 11:
Chart illustrating the difference between chronological age and dental age. A positive value shows that the chronological age is higher than the dental age, which means that the dental age is delayed. A negative value shows the opposite.

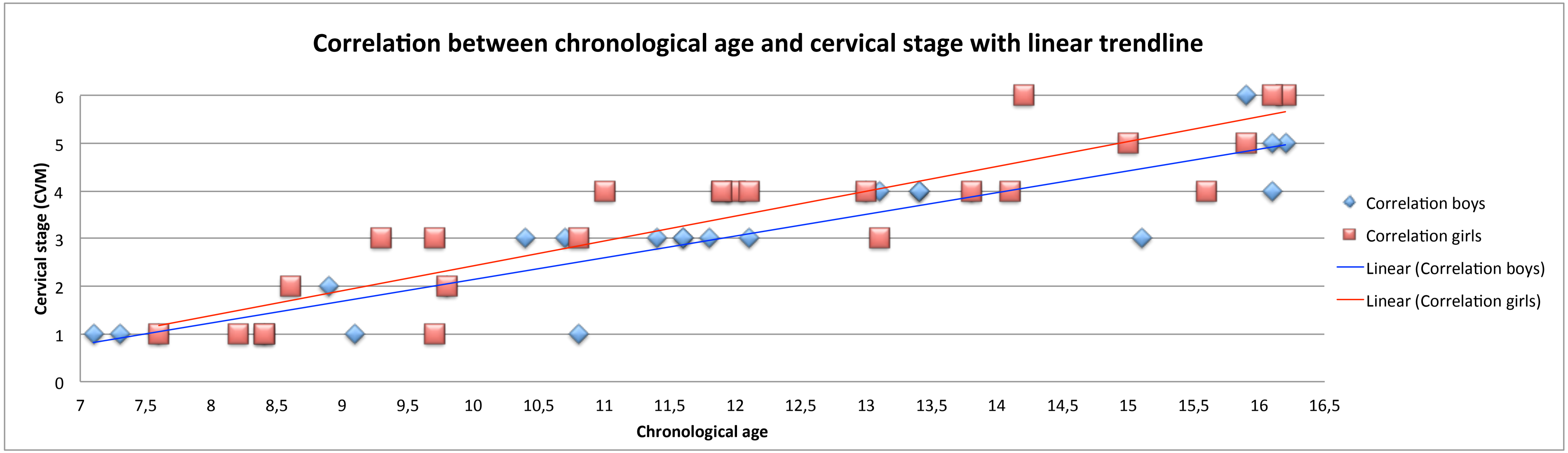

Figure 12:
Chart illustrating the correlation between chronological age and cervical stage.

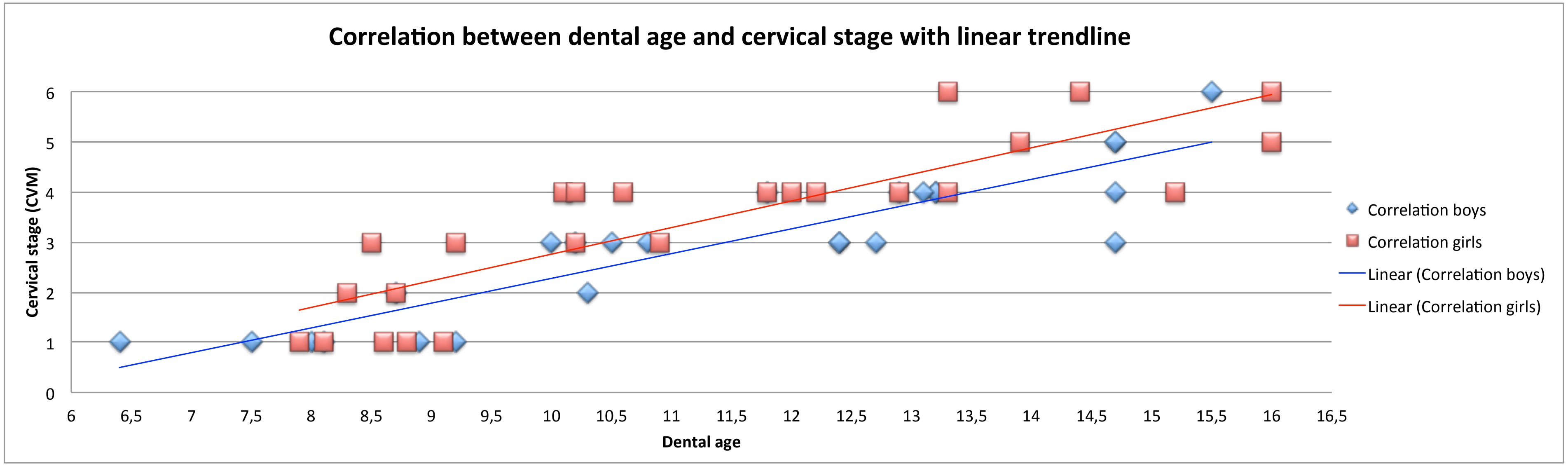

Figure 13:
Chart illustrating the correlation between dental age and cervical stage.

Tooth	0	A	B	C	D	E	F	G	H
Boys									
M_2	0.0	1.7	3.1	5.4	8.6	11.4	12.4	12.8	13.6
M_1				0.0	5.3	7.5	10.3	13.9	16.8
PM_2	0.0	1.5	2.7	5.2	8.0	10.8	12.0	12.5	13.2
PM_1		0.0	4.0	6.3	9.4	13.2	14.9	15.5	16.1
C				0.0	4.0	7.8	10.1	11.4	12.0
I_2				0.0	2.8	5.4	7.7	10.5	13.2
I_1				0.0	4.3	6.3	8.2	11.2	15.1
Girls									
M_2	0.0	1.8	3.1	5.4	9.0	11.7	12.8	13.2	13.8
M_1				0.0	3.5	5.6	8.4	12.5	15.4
PM_2	0.0	1.7	2.9	5.4	8.6	11.1	12.3	12.8	13.3
PM_1		0.0	3.1	5.2	8.8	12.6	14.3	14.9	15.5
C				0.0	3.7	7.3	10.0	11.8	12.5
I_2				0.0	2.8	5.3	8.1	11.2	13.8
I_1				0.0	4.4	6.3	8.5	12.0	15.8

Table 1: Self-weighted scores for tooth formation stages. Mandibular left side, seven tooth system according to Demirijan and Goldstein.

Age	Boys	Girls
3.5	21.9	20.4
3.6	22.4	21.2
3.7	23.1	21.8
3.8	23.9	22.6
3.9	24.8	22.9
4.0	**26.6**	**25.4**
4.1	26.8	29.8
4.2	28.0	31.0
4.3	28.3	31.4
4.4	29.7	33.2
4.5	31.4	33.2
4.6	32.5	34.4
4.7	32.7	35.3
4.8	33.7	35.3
4.9	35.0	35.7
5.0	**35.3**	**36.3**
5.1	36.0	37.3
5.2	37.7	38.5
5.3	38.7	40.2
5.4	40.3	41.5
5.5	41.0	43.2
5.6	42.2	44.3
5.7	44.7	44.5
5.8	45.8	45.2
5.9	47.1	48.4
6.0	**47.8**	**49.2**
6.1	48.1	51.3
6.2	49.5	53.7
6.3	50.3	54.5
6.4	51.5	57.4
6.5	52.6	57.8
6.6	54.5	60.8
6.7	57.2	62.3
6.8	58.7	63.5
6.9	61.4	64.9
7.0	**62.1**	**66.6**
7.1	62.7	68.5
7.2	63.1	71.0
7.3	63.9	82.0
7.4	65.4	74.8
7.5	65.8	75.1
7.6	66.0	75.7
7.7	67.3	76.5
7.8	68.4	77.1
7.9	70.2	78.0

Age	Boys	Girls
8.0	**71.3**	**79.3**
8.1	73.0	79.9
8.2	76.7	80.1
8.3	77.4	81.5
8.4	78.9	81.6
8.5	79.9	82.9
8.6	81.0	83.4
8.7	81.2	85.4
8.8	82.0	85.6
8.9	84.0	86.2
9.0	**85.0**	**86.9**
9.1	85.0	88.6
9.2	85.2	89.0
9.3	85.5	90.3
9.4	85.8	91.3
9.5	86.1	92.5
9.6	86.5	92.9
9.7	87.0	93.3
9.8	87.5	93.5
9.9	88.1	93.5
10.0	**88.5**	**93.6**
10.1	89.0	93.6
10.2	89.7	93.7
10.3	90.5	93.7
10.4	91.0	93.9
10.5	91.6	94.1
10.6	92.7	94.1
10.7	93.1	94.5
10.8	93.6	94.7
10.9	93.8	95.3
11.0	**94.0**	**96.4**
11.1	94.4	96.5
11.2	94.8	96.6
11.3	94.9	96.7
11.4	95.0	96.7
11.5	95.0	96.8
11.6	95.0	96.9
11.7	95.0	97.1
11.8	95.1	97.3
11.9	95.1	97.4
12.0	**95.2**	**97.6**
12.1	95.3	98.0
12.2	95.4	98.1
12.3	95.7	98.3
12.4	96.0	98.4

Age	Boys	Girls
12.5	96.6	98.6
12.6	96.9	98.7
12.7	97.0	98.8
12.8	97.1	98.8
12.9	97.2	98.9
13.0	**97.2**	**98.9**
13.1	97.2	99.0
13.2	97.4	99.0
13.3	97.8	99.0
13.4	97.9	99.0
13.5	97.9	99.1
13.6	98.0	99.1
13.7	98.0	99.2
13.8	98.1	99.2
13.9	98.2	99.3
14.0	**98.2**	**99.3**
14.1	98.4	99.3
14.2	98.5	99.4
14.3	98.6	99.5
14.4	98.8	99.5
14.5	99.0	99.6
14.6	99.1	99.6
14.7	99.2	99.7
14.8	99.3	99.7
14.9	99.4	99.7
15.0	**99.4**	**99.7**
15.1	99.5	99.7
15.2	99.5	99.8
15.3	99.5	99.8
15.4	99.6	99.9
15.5	99.6	99.9
15.6	99.6	100.0
15.7	99.7	100.0
15.8	99.7	100.0
15.9	99.7	100.0
16.0	**99.8**	**100.0**

Table 2: Dental maturity scores and the corresponding dental ages in a series of Finnish children.

Patient nr.	Chronological age	Rank	Dental age	Rank	Cervical stage	Difference K - D
Girl 1	8,4	1	8,6	1	CS1	-0,2
Girl 2	7,6	1	7,9	1	CS1	-0,3
Girl 3	8,4	1	8,8	1	CS1	-0,4
Girl 4	8,6	1	8,3	1	CS2	0,3
Girl 5	8,2	1	8,1	1	CS1	0,1
Girl 6	10,8	2	10,2	2	CS3	0,6
Girl 7	9,3	2	9,2	2	CS3	0,1
Girl 8	9,7	2	9,1	2	CS1	0,6
Girl 9	9,8	2	8,7	1	CS2	1,1
Girl 10	9,7	2	8,5	1	CS3	1,2
Girl 11	11,9	3	11,8	3	CS4	0,1
Girl 12	12	3	10,6	2	CS4	1,4
Girl 13	11	3	10,1	2	CS4	0,9
Girl 14	12,1	3	12	3	CS4	0,1
Girl 15	11,9	3	12,2	3	CS4	-0,3
Girl 16	13,1	4	10,9	2	CS3	2,2
Girl 17	14,1	4	13,3	4	CS4	0,8
Girl 18	13	4	12,9	3	CS4	0,1
Girl 19	13,8	4	10,2	2	CS4	3,6
Girl 20	14,2	4	13,3	4	CS6	0,9
Girl 21	16,2	5	14,4	4	CS6	1,8
Girl 22	15	5	13,9	4	CS5	1,1
Girl 23	15,6	5	15,2	5	CS4	0,4
Girl 24	16,1	5	16	5	CS6	0,1
Girl 25	15,9	5	16	5	CS5	-0,1
Boy 1	7,3	1	8	1	CS1	-0,7
Boy 2	8,9	1	8,7	1	CS2	0,2
Boy 3	7,1	1	7,5	1	CS1	-0,4
Boy 4	7,6	1	6,4	1	CS1	1,2
Boy 5	8,4	1	8,1	1	CS1	0,3
Boy 6	9,8	2	10,3	2	CS2	-0,5
Boy 7	9,1	2	9,2	2	CS1	-0,1
Boy 8	10,7	2	10,5	2	CS3	0,2
Boy 9	10,4	2	10,2	2	CS3	0,2
Boy 10	10,8	2	8,9	1	CS1	1,9
Boy 11	11,6	3	12,7	3	CS3	-1,1
Boy 12	11,4	3	10,8	2	CS3	0,6
Boy 13	11,8	3	12,4	3	CS3	-0,6
Boy 14	11,6	3	10	2	CS3	1,6
Boy 15	12,1	3	12,4	3	CS3	-0,3
Boy 16	13,8	4	12,9	3	CS4	0,9
Boy 17	13,4	4	13,2	4	CS4	0,2
Boy 18	13,4	4	13,2	4	CS4	0,2
Boy 19	13,1	4	11,8	3	CS4	1,3
Boy 20	13	4	13,1	4	CS4	-0,1
Boy 21	16,1	5	14,7	4	CS4	1,4
Boy 22	15,1	5	14,7	4	CS3	0,4
Boy 23	16,2	5	14,7	4	CS5	1,5
Boy 24	15,9	5	15,5	5	CS6	0,4
Boy 25	16,1	5	14,7	4	CS5	1,4

Rank	
1	7,0 to 8,9 years
2	9,0 to 10,9 years
3	11,0 to 12,9 years
4	13,0 to 14,9 years
5	15,0 to 17,0 years

Table 3: The subjects' chronological age and dental age classified in different ranks, cervical stage and the difference between chronological age and dental age in the right column.