Comparison between different scoring methods in age assessment using third molar around the age of 18years

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Abstract

The aim of this study was to look at the normal variability in third molar development in 18 years old, and to compare 2 scoring systems and 5 tables for dental age estimation. In addition to see how well they corresponded to each other and compare user friendliness. Two independent observers have collated and analyzed 269 panoramic radiographs with regard to the development of all third molars present, The variation in third molar development in 18 years old was found to vary from early root development stages, to complete root formation, with the main concentration around the later stages of root formation. Males developed third molars earlier than females, and the maxillary third molar develop earlier than the mandibular. The age estimation tables according to Mincer was found to have the highest prevalence of dental age at 18 years for both male and female, and is the most accurate system of the five systems studied. The scores according to Demirjian were considered the most user- friendly and easy-to-use system.

Innhold

Preface

Forensic odontology has a small place in the world of clinical odontology, but is unique in the sense of opportunity for dentists to cooperate across professions – like the national criminal investigation service and pathologists. Estimating dental age is an important contribution to the community, and the increase in worldwide migration of people tells us that the need for forensic odontologists will increase.

The work of this master thesis started spring of 2015 with an application to the Regional Committees for Medical and Health Research Ethics. Access to patient orthopantogram radiographs (OPGs) from the Faculty of Dentistry in Oslo was granted, and summer of 2015 was spent in a dark room viewing 785 OPGs, before we had the 269 OPGs we graded for dental age.

We both have had a growing interest in dental age estimation during the work of this master thesis, and we have learned a lot from many different research papers, and from devoted forensic odontologists along the way. A special thanks to our supervisor assoc prof Sigrid Kvaal, who has been of indispensable help during the work and disposition of this research. Thanks to the Department of Community of Oral Health and the Department of Radiology at the Faculty of Dentistry, University of Oslo.

Enjoy our master of thesis.

Introduction

Over the years there has been increasing demands for age assessment all over the world because of age restrictions in many parts of the modern society. Examples are driving license, marriage age, age of legal responsibility, child labor, in sports with competing age-ranges in events like the Youth Olympics and World Championships, in forensic investigations, in cases with victims of trafficking suspected to be minors, and immigrants without valid identification papers claiming to be unaccompanied minors. We are experiencing increased migration, internal disturbances within countries and across borders, in many countries there are no traditions or ability to register date of birth and many people do not have valid identification papers.

In the nineteenth century, during the industrial revolution in Great Britain, children were expected to work, to support their families. The work situation changed from large working fields in open air, to small industrial spaces with poor working conditions. Long hours, dangerous tools, low pay and physical punishment resulted in laws against child labor; the first milestone was the Factory Act of 1833. (1)

In the years from the industrial revolution until now, the focus on children's rights have only escalated. In 1924 the Geneva Declaration of the Rights of the Child stated that "the child must be given the means requisite for normal development, both materially and spiritually" and "…must be protected against every form of exploitation."(2) In 1990 the Convention on the Rights of the Child became an international law. The law states, among others, that the child has the right to be protected from harmful influences, abuse and exploitation. The convention defines a child as "every human being below the age of eighteen years unless under the law applicable to the child, majority is attained earlier"(3).

Today, the number of children in child labor is 168 million, the largest number being in Asia and the Pacific, with 78 million children in labor (9, 3% of child population) (4).

A problem that arises in the shadow of this development is adults that exploit these laws for their own benefit. Laws have been formed since 1833 to protect and improve the rights for children, so that adults do not take advantage of their vulnerable position.

One problem in the immigration situation is where several asylum seekers arrive without reliable identification papers, intentionally for some, and unintentionally for others. Unaccompanied minors have more rights than adult asylum seekers; they have the right to education, healthcare and to be reunited with their families.

Statistics from the Norwegian directorate of immigration states that 1204 of 11480 asylum seekers in 2014 claimed that they were under the age of 18 years. (5, 6) In 2015 the total number of asylum seekers escalated to 31145, where 5297 claimed to be under the age of 18 (7). To prevent exploitation of the children's rights during asylum seeking, the Norwegian Government has decided that an age determination should be performed when there is uncertainty about the reported age. The introduction of age determination has several aspects, both to reduce the amount of adult asylum seekers trying to seek asylum on false pretenses, and to prevent adult asylum seekers to take a place in the community that has been reserved for a child. Numbers from 2003-2004 states that more than 60% of the supposed under aged asylum seekers were, indeed, older than 18 years of age. This only proves the importance of age determination to prevent exploitation of the law (8). Justice for the children are the main goal, any exploitation of the rights must be condemned.

Each country or legal jurisdictions have their own method for age estimation and many use a combination of methods. A review published in Forensic Science International by A. Schmeling et al. (9) recommend that “for determining the age of live subjects a forensic age estimate should combine the results of a physical examination, an X-ray of the hand and a dental examination which records dentition status and evaluate an orthopantogram (OPG)”. They also recommend that the examination is carried out by an expert with forensic experience and include a discussion of the age relevant variations, such as genetic, ethnic and socio-economic status.

A physical examination includes measures such as body weight, height and constitutional type, and visible signs of sexual maturity. This examination should only be done in conjunction with skeletal maturity evaluation and tooth development, since the physical examination shows the largest range of variation. The examination is also done to rule out any visible signs of age related diseases, and to check if skeletal age and tooth age correspond to the physical development.

Skeletal examination consists of an X-ray of the left hand. The pediatric radiologist looks at the timing of development of each bony part and their epiphyseal region, the degree of mineralization of epiphyseal ossification and the extent of fusion between the epiphyseal region and the relating bone. This is done by comparing the X-ray with a radiographic atlas, using images of relevant sex and age. According to atlases, the skeletal development of the hand completes at the age of 17 in females, and at the age of 18 in males. Standard deviation in this examination ranges from 0, 6 – 1, 1 years with the use of Greulich-Pyle radiographic atlas, or from 0,2 – 1,2 years with the use of Thiemann-Nitz radiographic atlas (9).

Emerging adults is a difficult age group to assess, but an important one by the reasons described above. None of the methods available for age estimation can accurately determine chronological age. By the age of 18 years the secondary sex characteristics are all developed and calcification of the epiphyseal bones is almost or fully complete. Both of these methods are also highly influenced by nutritional status and other environmental factors. Psychological age assessments is not based on any biological measurements, and have few evidence based findings. According to Mohammed et al.(10) dental age evaluation is a reliable indicator of chronological age. The teeth have several advantages; a continuous and progressive process that can be followed radiographically, they can be evaluated at each examination, the examination is not invasive and the teeth are not influenced by nutritional status and environmental factors. For assessment of young adults and adolescents the third molar is one of few body features that complete its development after puberty and hence a good indicator to use in age assessment in emerging adults, but have disadvantages of being highly variable in morphology and may be congenitally missing.

Most of the research related to dental age compares the accuracy of different methods or a single method to a sample of individual OPGs with known chronological age. This is important research to ensure that the methods can be used to estimate age close to chronological age (10-15). These studies grade several hundreds to some above a thousand OPGs in their studies, but the quantity per age is seldom above 100 OPGs. This is because a large age span is included, from 9-20 years (12), 3-16 years (13), 12-25years (14), 4-34 years (15). Lewis et al. (11) reviews principles, methodology and population data for the most commonly used technique in the United States, and here they also refer to articles with large age span like the articles mentioned above. A shorter age interval and a larger sample size will improve the reliability of our findings, since a high sample size is more likely to include the biological variation. A recently published article by Philipp Streckbein et al. (16) - is of interest because their aim is to "analyze the correlation between third molar calcification stages and age, focusing on legally important ages, 17 and 18 year olds" The article is similar to this study but use a different angle and a wider age span (15-22 years), but still they have a large sample among ages between 17-18 years for both gender (400 female and 300 male). They have come to the conclusion that the lowest calcification stage of all present third molars is useful in determination of an age at or over 18 years.

Age estimation is frequently debated in asylum applicant countries (17), but only one recommendation referred to general principles for age estimation on unaccompanied minors (9). This study also has a part two, (18) here they want to study how ethnic origin can influence tooth mineralization. This is currently also a highly debated topic, which will be mentioned in the discussion, but not go further into in this study.

The aim of this study is twofold
1) To look at the normal variability in third molar development in 18 years old.
2) To compare the five most common age estimation methods using two different scoring systems, to see how they relate to chronological age and user friendliness.

Permission has been obtained from REK (Regional Committees for Medical and Health Research Ethics) to gain access to OPG radiographs from the patient's archives at the Faculty of Dentistry, University of Oslo, for our research, (2015/704)

Terminology:
Chronological age = the period of time or number of years elapsed to any point of time after the date of birth
Dental age = measure of dental development based on the number of permanent teeth and their development
Dental age assessment = an expertise in dental medicine which aims to define the most accurate way to estimate the dental age of a person.
Minor =a person under the age of full legal responsibility.
Unaccompanied minor asylum seeker = third country national or stateless persons below the age of 18 who arrive in the territory of the member states unaccompanied by an adult responsible for them, whether by law or custom, and for as long as they are not effectively taken into care of such person, or minors who are left accompanied after they have entered the territory of the member states.
OPG = a modification of pantomography in which the X-ray beam is kept perpendicular to the jaws, producing a flat image of both jaws and their teeth.

Materials and methods

OPG radiographs were collected from 785 persons, who had attended the Faculty of Dentistry, Institute of Clinical Dentistry, in University of Oslo with the following inclusions criteria:
1) National identification (ID)-number
2) OPG radiographs taken the calendar year that the person reached 18 years

Exclusion criteria were:
1) Incomplete or temporary National ID-number (temporary residents)
2) OPG radiographs not taken in the calendar year they reached 18 years
3) An incomplete dentition (less than 32 teeth)
4) Pathology that inhibited or delayed third molar development
5) Poor quality radiograph
6) Bony structure superimposing third molar root development

This resulted in 269 OPG radiographs, 133 from females and 136 from males. Two independent observers first trained and calibrated a sample of ten OPG radiographs. Then the two observers analyzed the radiographs together. Each of the four third molars were scored by both observers together, using two different scoring systems:
1) Moorrees, at al. (19) - 14 formation stages with radiographs and text description, and
2) Demirjian et al. (20) - 8 formation stages with drawings and text description.

Dental age was found by entering the scores into the equations or readings from the tables of the following:
1) K. Mesotten et al. – Dental age estimation and third molars: a preliminary study (21)
2) K. Haavikko – The formation and the alveolar and clinical eruption of the permanent teeth. An orthopantomographic study (22)
3)H. M. Liversidge – Timing of the human mandibular third molar formation (23)
4) H. H. Mincer et al. – The A. B. F. O. Study of third molar development and its use as an estimator of chronological age (24)
5) J. C. Mitchell et al. – Dental age assessment (DAE): Reference data for British Caucasians at the 16 year threshold (25)

Special considerations were made when the authors assessed dental age using the specific tables:

1) Liversidge have specific tables for when the tooth is "entering the stage" and when the tooth is "In a stage», specified for "Africans", "Cape colored children", "Bangladeshi children in London" and "White children in London". In the sample, the authors used the tables from "white children in London" "In a stage", because this seemed to represent the sample the best. Because of no mean age in the Ac stage in table 3, the authors used the Ac score from the "Mean age of entering stage (in years) of white children In London". (23)

2) Haavikko: Ri is not present in the scoring table; the authors choose to convert all the Ri stages to Crc when estimating dental age.

The authors randomly selected 20 OPGs which were assessed at the start of the research and at the end, 5 weeks later. An experienced forensic dentist also assessed the same 20 OPGs. The results were compared by calculating intra-observer agreement and inter-observer agreement using Cohens Kappa regression analysis in IBM SPSS Statistics 22 program (Statistical Package for the Social Sciences). It is a more robust measurement of intra-observer agreement and inter-observer agreement than simple agreement calculation because it takes agreement by chance into consideration.

The chronological age, date of OPG, gender and the two different scores of third molars were registered in Microsoft Excel 2010, and statistics were carried out in Microsoft Excel 2010. The scores from each person were converted into a dental age using the tables from each method. The dental age per person were used to find differences between chronological age and dental age.

Gender, data from chronological age and the scores registered in Microsoft Excel were exported and analyzed using IBM SPSS Statistics 22 (Statistical Package for the Social Sciences), for the purpose of graphically illustrate the sample based on age categories, gender and stage frequency for each method. The development stages, estimated for each of the four third molars in each individual with the different methods, was used to find the normal variation of third molar development in the sample.

Because of possible inter correlations between the third molars it was decided to display figures based on 3rd molar teeth from the same side of the jaw, hence tooth 28 and 38 (figure 2-5).

Figures 2 and 3 shows the frequencies of the age categories for each stage in a modified Moorrees et al. To make the figures easy to understand and interpret, and easy to compare with figures 4 and 5 we had to display the results merging three methods (Liversidge, Mesotten and Haavikko) that have based their scores on Moorrees et al. system. Each of the three methods have removed and added stages to Moorrees et al. original version. All three methods have removed stage 8A - cleft minimal, 8B - cleft rapidly enlarging, 10 - 1/3 root, 12 - 2/3 root, and called stage 14 – divergent root canal walls for R3/4, and stage 15 - convergent root canal walls for Rc. Liversidge and Mesotten have also added stage A1/2 and Ac, while Haavikko have added stage Ac. All three methods have some of the stages in common, and these stages are shown in the diagrams in figure 2 and 3. For Liversidge those from the sample that were put in stage Rcl and A1/2 have been added to stage Ri and Rc respectively. Those in the sample that were put in stage A1/2 in Mesotten have been added to stage Rc. This merging is in this paper called "the modified Gleiser and Hunt system" because Morrees et al. system has its origin for Gleiser and Hunt (26).

Results

Normal variation

Since the sample consists of OPG radiographs taken in the calendar year the persons turns 18 years, figure 1 shows the distribution of age in years and month, based on categories whether the person has taken the radiograph before or after their 18th.birthday. The sample is a good representative for the population wanted to be studied because it shows that the majority of the sample is near 18,0 years, enhanced by that the mean age of the sample, for both males and females, are 18,0 years.

Figure 2 shows the frequency of stages according to "the modified Gleiser and Hunt system" in respect to gender and age categories in tooth 28. The genders have in common that the majority of the sample lie in the later root stages, but for females the sample are more dispersed in all the stages than for males. In addition the two age categories, where the sample is under 18,0 year, is overrepresented in the earlier stages. The opposite is true for the later stages in both genders. The age category "18, 0-18, 4 years" have the highest peak for both males and females in stage Ac.

Figure 3 shows the frequency of stages according to "the modified Gleiser and Hunt system" with respect to gender and age categories in tooth 38. The diagrams for the females shows that the sample are more evenly dispersed for all the root stages, than for tooth 28 (figure 2) with the highest peak for root stage Rc. The early root stages are overrepresented in the two age categories under 18.0 years and the opposite for the late root stages. The diagrams for the males show some of the same tendency as for the female, but have the majority of the sample in the later stages, with the highest peak in root stage Rc.

Figure 4 shows the frequencies of stages with respect to gender and age categories for the Demirjian system in tooth 28. In general the majority of the sample for both genders lies in the later root stages with the highest peak in stage H in the age category "18,0-18,4 years". The two age categories from 18,0 years and older is overrepresented in the last two stages of root formation. For females the sample is more dispersed for each stage than for males.

Figure 5 shows the frequencies of stages with respect to gender and age categories for the Demirjian system in tooth 38. In females the sample is more evenly dispersed between the stages than for tooth 28 (figure 4) and with the majority of the sample in root stages F and G. Age category "18,0-18,4 years" have the highest peak in stage F. The same pattern is shown for the males but is more skewed to the later root stages than for females. Age category "18,0-18,4 years" have the highest peak in stage G.

By comparing the two systems based on the figures 2-5 with respect to gender and age category, (fig. 2-5) there are not many differences. Both have in common that:
1) The females are more dispersed between the stages than for males.
2) The majority of the sample lies in the later root stages.
3) There are differences in development between the maxillary and mandibular third molars The results indicate faster root development in the third molars of the upper jaw.
4) There is a small group, especially among the females, that have third molars in the early root stages which can make it difficult to estimate the correct chronological age.

Dental age estimation

Fig. 6 shows the frequency of the different scoring stages in root formation at 18 years of age, when Demirjian's scores was used, in both males and females. The graph illustrates the same tendency as for the other methods.

Fig. 7 illustrates the frequency of the root formation stages at 18 years of age, when Demirjian method is used, in maxilla and mandibula, for both males and females. The graph shows the same tendency as for the other methods.

Fig. 8 displays the dental age assessed for each male person, and spread of all the dental ages for males based on tables from Mincer. The black horizontal line illustrates the mean chronologic age (18 years), and the red line illustrates the mean dental age (18, 8 years), and shows that the mean dental age overestimates approximately with 1 year.

Fig. 9 illustrates the frequency of difference between dental age and chronologic age, in male. Mincer shows a frequency of more than 40 with no difference, but the same for 1 year of overestimation. The histogram shows that Mincer has a tendency of overestimating age.

Fig. 10 illustrates the frequency of difference between dental age and chronologic age, in females. Mincer shows a frequency of more than 30 with no difference, but almost the same for 1 and 2 years of overestimation.

Comparison of all methods

Table 1 lists the average dental age results and standard deviation from all five methods, comparison of the results shows mostly overestimating dental age compared to chronologic age, while DAE has a slight underestimating, as is for females by the Haavikko scoring system.

Fig. 11 compares the frequencies of dental age assessed from the five different methods, for males, outlined for the methods based on Demirjian (20) (Mitchell and DAE). Mincer show the narrowest range in dental age, from 16,5 to 21 years, and a peak of 19 samples around 18 years, but also a 19 sample peak at 20,5 years. DAE has a broader range, with a peak of 20 samples at 19,5years.

Fig. 12 compares the frequencies of dental age assessed from the five different methods, for males, outlined for methods based on Moorrees, et al. (19). All three shows approximately the same dental age range, only Mesotten has a peak at 18 years on less than 10 samples, Liversidge peak on 19,5 years with more than 40 samples, and Haavikko has a peak on 19 years with 30 samples.

Strength of agreement using Cohens Kappa regression analysis

Table 2 shows values for inter-observer agreement calculated using Cohens Kappa regression analysis. According to J. Richard Landis and Gary G. Koch (27), an article interpreting the values using this regression analysis method, the inter-observer agreement using Demirjian et al. show good to excellent agreement. The inter-observer agreement using Moorrees et al. show moderate to poor agreement.

Table 3 shows values for intra-observer agreement calculated using Cohens Kappa regression analysis. According to J. Richard Landis and Gary G. Koch (27), the intra-observer agreement using Demirjian et al. good agreement, while intra-observer agreement using Moorrees et al. show moderate to poor agreement.

Discussion

A big part of this research relayed on stage assessment by the authors, which is a subjective interpretation, and hence, subjected to many sources of error

- The quality of the radiograph and overlying structures superimposed on the third molars, especially in the upper jaw, being that an orthopantogram is a two-dimensional radiograph.
- Subjective interpretation of the radiographic illustrations, drawings and descriptions by Moorrees et al. and Demirjian et al.
- In situations where the teeth lies between two stages, as an example – when are the walls of the root "divergent" and when are the walls "parallel".
- Unexperienced authors – only assessed 10 orthopantograms, independently from this study.

Inter-observer agreement and intra-observer agreement in this study have shown poor to good agreement at best for stage assessing (see table 2 and 3). This agreement can be further improved by more experienced observers which have been calibrated in advance, using radiographic pictures together with descriptions of the stages, and to use relative measurements of the teeth together with the stage assessment. The Demirjian's scores showed better Cohens Kappa values than for the Moorrees's scores, this was also found by K.S. Dhanjal et al. (28) The reason for this can be that there are more stages in Moorrees et al. than for Demirjian et al. which makes it more difficult to place each teeth in the correct stage because there are less differences between the stages. There are also lower Cohens Kappa values for the maxilla than for the mandibula, which can be explained by more overlying structures in the maxilla than in the mandibula obscuring the third molar in the OPG. A study by Kullmann et al. (29) had the aim of "comparing intra-observer agreement and inter-observer agreement based on subjective assessments of stages of root development with objective measurements with a digitizer." They found that for both subjective and objective procedures late development stages are the most unreliable to assess, and that it accounted for most of the disagreement in both intra- and inter-observer agreement

Another way of more accurate stage assessing is the use of Cone-Beam Computed Tomography (CBCT). Here you get a three dimensional view of the molars and less noise from overlying structures. Together with relative measurements/or new parameters the stage assessments might be more accurate and less influenced by subjective interpretation. Today the technique is under development and there a few studies that have been done and the sample size is generally low (30). This is because as of today the CBCT machines give higher radiation dose than an OPG- radiograph, they are less available as the machines are quite expensive and there is a need to develop a large database and available software to process the data (31).

There is also always a chance of human errors when conducting the practical part of the research:

- Mismatch between the OPG being evaluated and the individual
- Deletions and switches in the lists when exporting and importing data between programs. This error could then be transferred when calculating dental age and making figures and tables.
- The authors have minimized the risk for such errors by cross checking OPG with the right individual and the transfer of data.

Normal variation

This research was carried out to look at the normal variation in third molar development in persons in their 18th year of age. This is of interest because the development of the third molars is used in dental age estimation, which can contribute to the assessment of chronological age when this is not known in several critical situations as described in the introduction.

Most teeth were in the late root formation stages, shown in figure 2-5. Some individuals in the sample were in the earlier root formation stages, most of these were aged closer to 17, 5 years, but there are also some individuals that are 18,0 years and older. The study show heterogeneity in third molar development, which is also shown in the article by Streckbein et al. (16), but with a different aim of the study. The diversity of the third molar development in 18 year olds is not surprising as the literature itself cannot conclude at which age the root development is finished. There are often large standard deviations for each stage of the methods we have tested here (21-25), as is the same in textbooks, in the chapters under tooth development (32, 33). In Illustrated embryology, histology and anatomy by Fehrenbach et al. (33), there are no references to the age range for root development. Root development in teeth are a continuous process and there is no method that can follow this development step by step. This is why there is no “accurate age” at which each stage is beginning or finishing. In addition the processes which underlie root development is influenced by genetic factors, different for each individual. As mentioned earlier in this discussion, page 14, paragraph 3, new ways and different parameters might make dental age estimation more accurate and more individually designed.

The variation in our sample showed differences between male and female with males having a higher frequency of the later root development stages than females. This suggests that males develop faster during late root formation. This is also shown in other studies (34). Females have a more evenly dispersed frequency between all root stages. Since our sample has an age distribution and a mean value of 18 years for both males and females, in addition to a 50/50 ratio of both genders, the results should reflect the normal variation of a population of 18 years old individuals. Because of sexual dimorphism dental age tables should be sex specific (11).

The sample is from Norwegian population and therefore might include persons of other ethnic groups, like adopted people and immigrants. The tables used to estimate dental age are in some studies ethnic specific, and will therefore not be correct for all subjects in our sample. Two studies by Thevissen et al. have showed that ethnic differences in third molar development are minimal (35, 36). In these two studies the researchers have used the same sample for both. The aim of the first study was to evaluate country specific third molar development on standardized collected and analyzed data. The conclusion was that there were significant differences between countries in speed and onset of development, but that the differences in actual value were small, had an irregular pattern and was age dependent, with the differences smaller around 18 years. In the other study the aim was to collect country specific database of third molar development and to verify how related dental age estimations was influenced if they used dental development information only from Belgium or from all collected countries together. When using information from all countries pooled together compared to country specific information it provided a negligible average increase and that there was “no indication at all that not using country specific information influenced the percentage of correctly identified subjects”. We therefore believe that the ethnical difference have had minimal influence in our results. Our sample reflects the normal Norwegian population and is not the same populations that normally have dental age determined, but it is representative for the variations around the age of 18 years.

Anatomical structures close to or positioned in the eruption path of the third molar can influence the root formation. In our research, we have included third molars that seem to have normal root development despite obstructing objects, like the second molar tooth, because we consider this phenomenon as a part of the normal variation in a population. The influence on root formation on impacted teeth seems to show contradicting results in other studies. Friedrich et al. (37) showed that impaction of third molar had no influence of root formation, but Lauesen et al. (38) showed in his research that the root formation was delayed when the third molar is impacted. There are not enough studies conducted in this area to conclude either way, and if this can influence the third molar development there need to be studies to see how much this affects the accuracy of age estimation using impacted third molars.

Dental age estimation

As already mentioned several countries in addition to use different methods for assessing age, also use different scoring systems. Our five age estimation methods are the most used worldwide and we wanted to compare these. Either way, it is important that comparative systems are used so that individuals do not receive different ages, and maybe different rights, in another country.

The estimated time of apex closure is difficult; it is not possible to say exactly the time when apex is closed. This problem can be solved by using the stage before apex closed, or specific “entering stage” tables, if possible. The mean or median dental age when apex close is influenced by the sample used to make the tables, when the sample has high upper age limit, this will overestimate dental age, when apex closes.

All tables used in dental age estimation in this research has specific tables for each gender, this rules out any inter gender differences.

Mincer et al. (24) found that there are left-right asymmetry, and that the use of two third molars, one maxillary and one mandibular third molar, instead of only one third molar, shows significant statistically improvement in predictive accuracy when it comes to dental age assessment.

All methods overestimate age. The tables according to Mesotten et al. are skewed toward the upper age range (because the tables are based on a sample where more than 60% were between 19- and 22 years old). This may be the reason for the overestimation of dental age in our research, especially for males, where Ac has a high incidence. We expected a higher percentage of males in stage Ac than for female, because other studies indicate earlier closing of apex in males, than females.(23) as was also shown in our study.

The ABFO method (Mincer et al) has the highest prevalence of dental age at 18 years for both male and female, and is the most accurate system of the five systems we applied, in the specific age range of 18 years.

User friendliness

The scoring according to Demirjian's diagram was much easier and faster than Moorrees', because of fewer stages. Moorrees' system have many stages, and it is difficult to determine the correct stage because there are small differences between the stages. On the other hand, the observers felt that in several cases the stage was underestimated with Demirjian's scores because of the large gaps between the stages, especially between stage D and E, which also shows a big jump in age. This can result in an underestimation of dental age, but we did not experience this, maybe because the main stage in the 18^{th} years age group was stage G and H.

Mesotten use left side third molar when calculating dental age for male, and right side third molar when calculating for female. (Multicollinearity)

The sources of error with the scoring methods are human errors and lack of experience among the observers. To reduce the human errors as much as possible, data has been copied from the original patient list using copy and paste functions, and formulas in Excel are used to calculate the statistics.

Conclusions

In 18 years old person the stages in root development is close to being almost complete, but our research has shown dispersed third molar development, from early root development stages, to complete root formation. The individual differences and large span of development in each stage make it difficult to create tables with fixed dental age; this is illustrated by the large dental age intervals in all the tables. Further research should be made on larger samples to confirm these large intervals.

The ABFO tables (Mincer et al) has the highest prevalence of dental age at 18 years for both males and females, and is the most accurate system of the five systems we tested. We also consider the Demirjian's scoring system as the most user-friendly and easy-to-use system.

Our research confirms that across all methods and stages, one can conclude that the third molar develops earlier in maxilla than in mandibula, and that males have a faster root development then females.

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Appendix

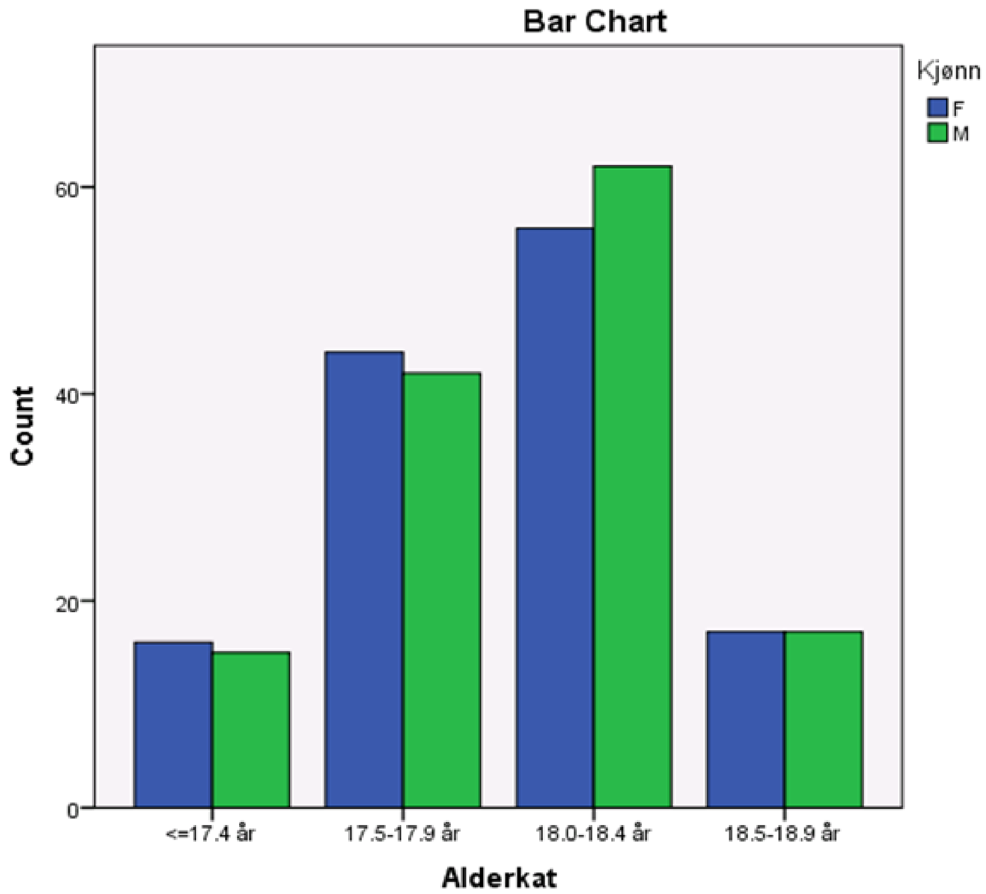

Fig. 1 Age distribution in year and month, in their 18th year, divided into categories. This figure show frequencies in each age category.

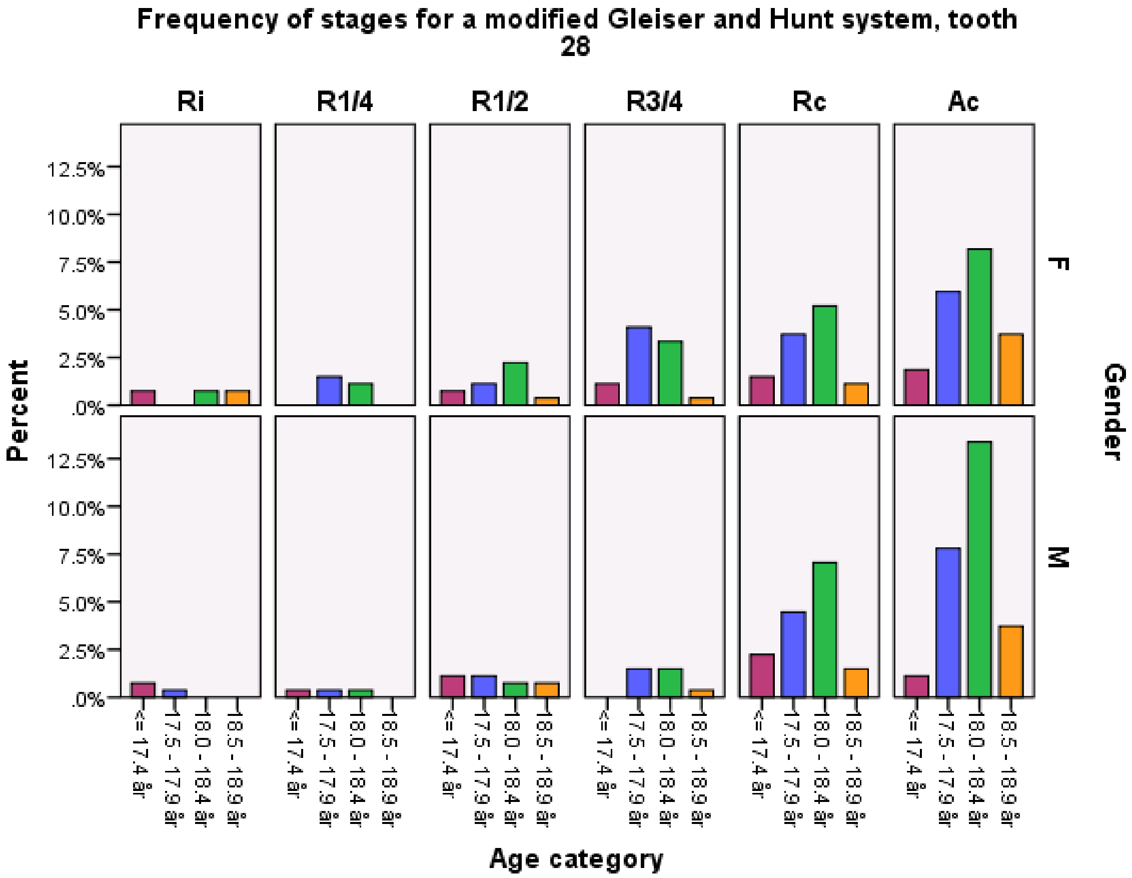

Fig. 2 Frequency figures in percent according to a modified Gleiser and Hunt system for tooth 28 with respect to age categories and gender. This system is a merging between Liversidge, Mesotten and Haavikko that have based their scores on Moorrees et al. system. Each of the three methods have removed and added stages to Moorrees et al. original version. All three methods have removed stage 8A - cleft minimal, 8B - cleft rapidly enlarging, 10 - 1/3 root, 12 - 2/3 root, and called stage 14 – divergent root canal walls for R3/4, and stage 15 - convergent root canal walls for Rc. Liversidge and Mesotten have also added stage A1/2 and Ac, while Haavikko have added stage Ac. All three methods have some of the stages in common, and these stages are shown in the diagrams in figure 2 and 3. For Liversidge those from the sample that were put in stage Rcl and A1/2 have been added to stage Ri and Rc respectively. Those in the sample that were put in stage A1/2 in Mesotten have been added to stage Rc. This merging is in this paper called "the modified Gleiser and Hunt system" because Morrees et al. system has its origin from Gleiser and Hunt (26).

The figure show the variation in third molar development among 18 year olds (in their 18^{th} year) based on stages in the development.

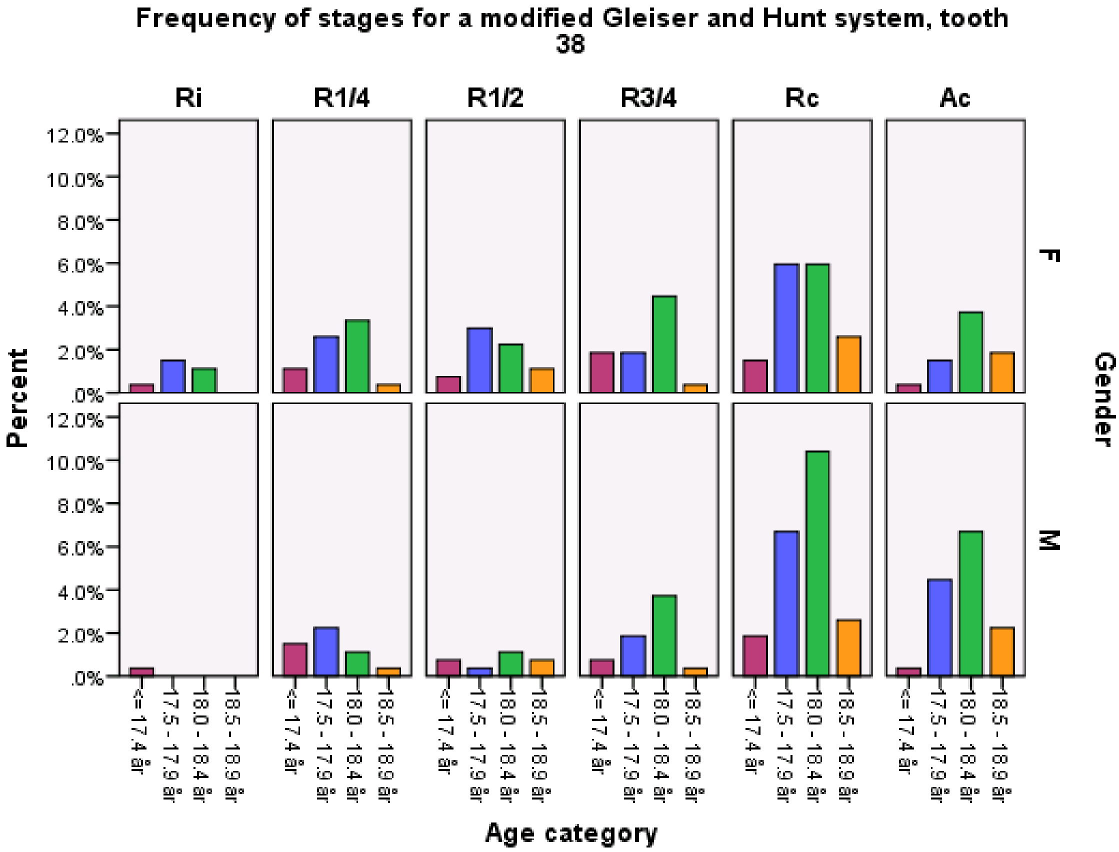

Fig. 3 Frequency figures in percent according to the modified Gleiser and Hunt system, for tooth 38 with respect to age categories and gender. This system is a merging between Liversidge, Mesotten and Haavikko that have based their scores on Moorrees et al. system. Each of the three methods have removed and added stages to Moorrees et al. original version. All three methods have removed stage 8A - cleft minimal, 8B - cleft rapidly enlarging, 10 - 1/3 root, 12 - 2/3 root, and called stage 14 – divergent root canal walls for R3/4, and stage 15 - convergent root canal walls for Rc. Liversidge and Mesotten have also added stage A1/2 and Ac, while Haavikko have added stage Ac. All three methods have some of the stages in common, and these stages are shown in the diagrams in figure 2 and 3. For Liversidge those from the sample that were put in stage Rcl and A1/2 have been added to stage Ri and Rc respectively. Those in the sample that were put in stage A1/2 in Mesotten have been added to stage Rc. This merging is in this paper called "the modified Gleiser and Hunt system" because Morrees et al. system has its origin from Gleiser and Hunt (26).

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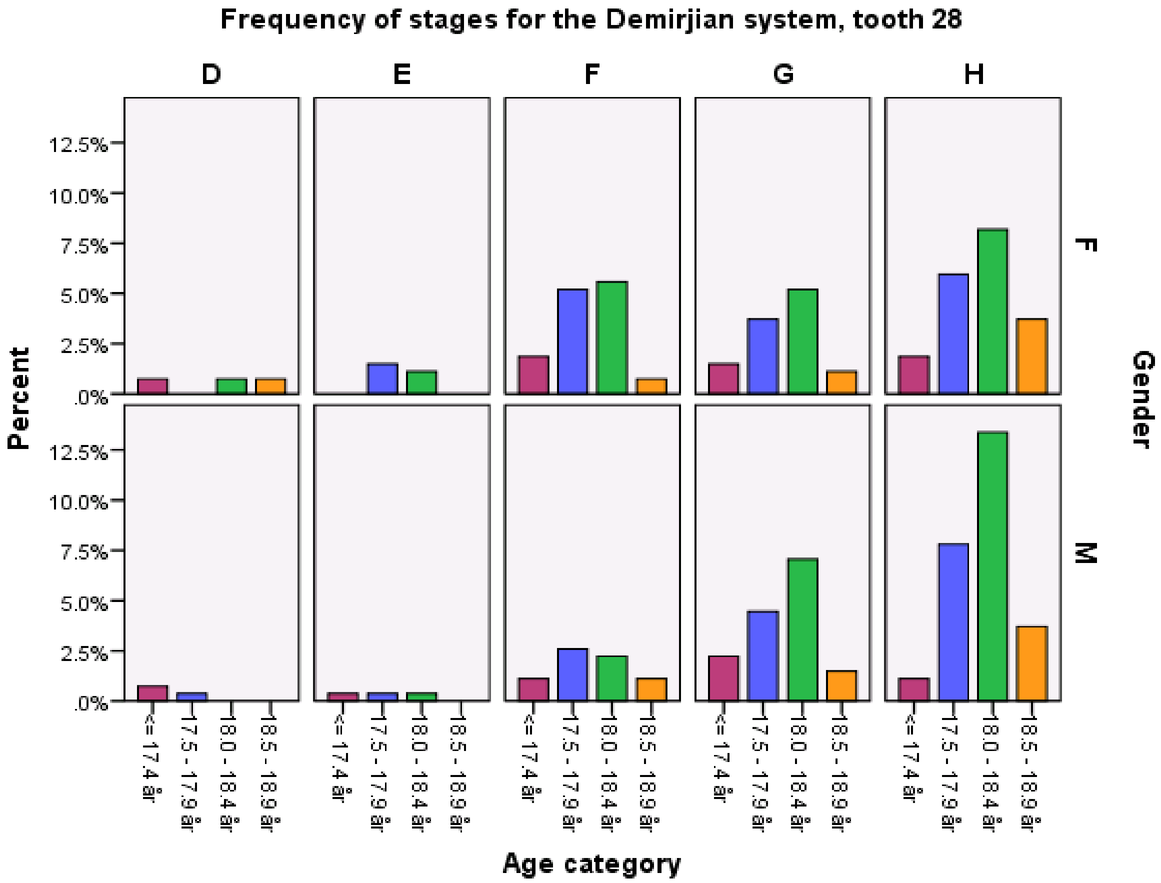

Fig. 4 Frequency figures in percent of the Demirjian et al. system, for tooth 28 with respect to age categories and gender. The figure show the variation in third molar development among 18 year olds (in their 18th year) based on stages in the development.

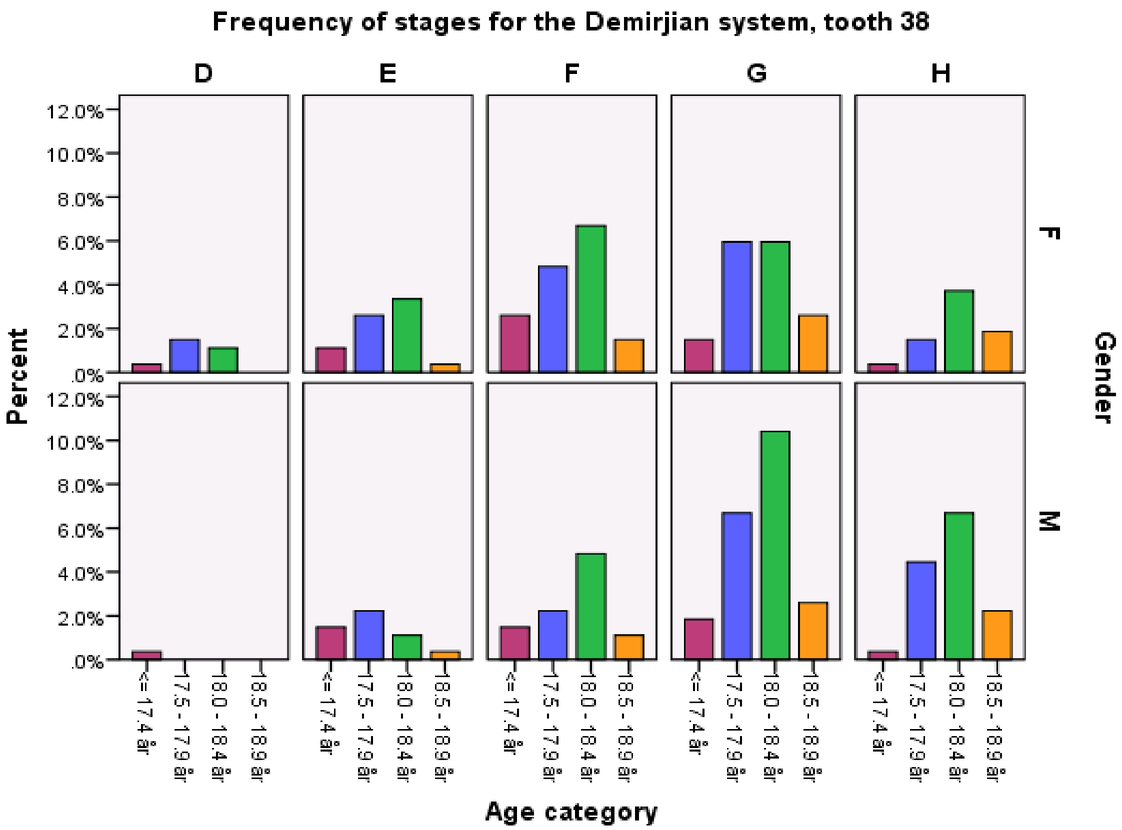

Fig. 5 Frequency figures in percent according to the Demirjian et al. system, for tooth 38 with respect to age categories and gender. The figure show the variation in third molar development among 18 year olds (in their 18th year) based on stages in the development.

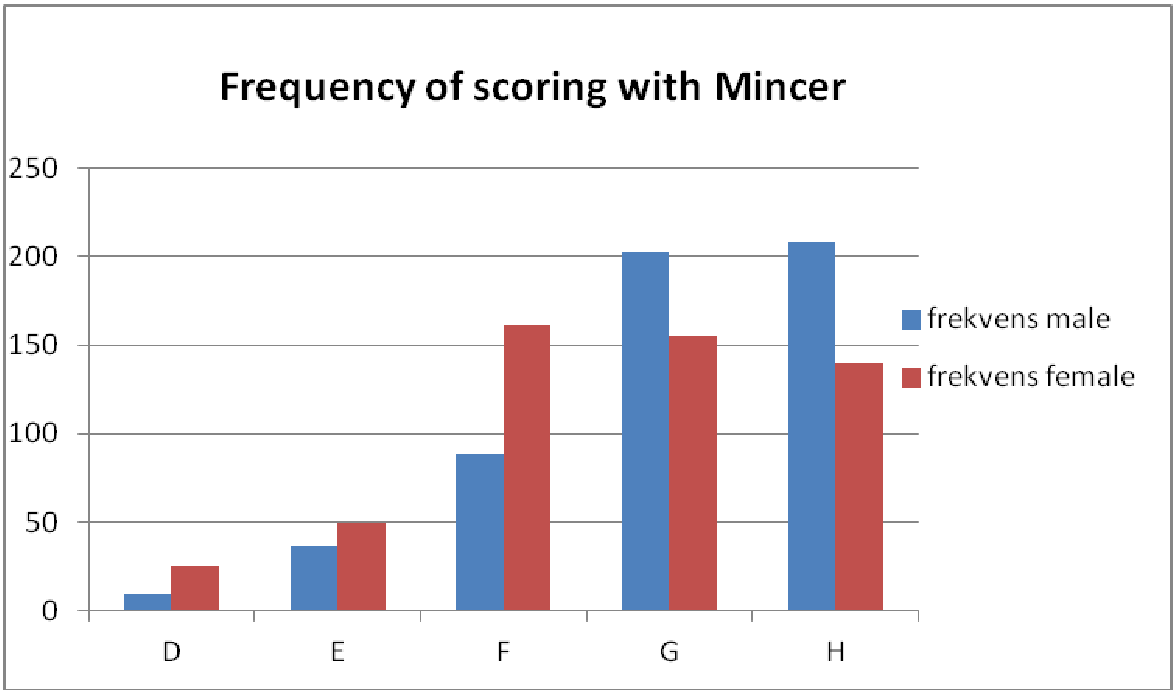

Fig. 6 Frequency of stages when scoring with Mincer tables of third molar grading (24). N (females) = 532, N (males) =544. Males have a higher frequency of later stages, than females.

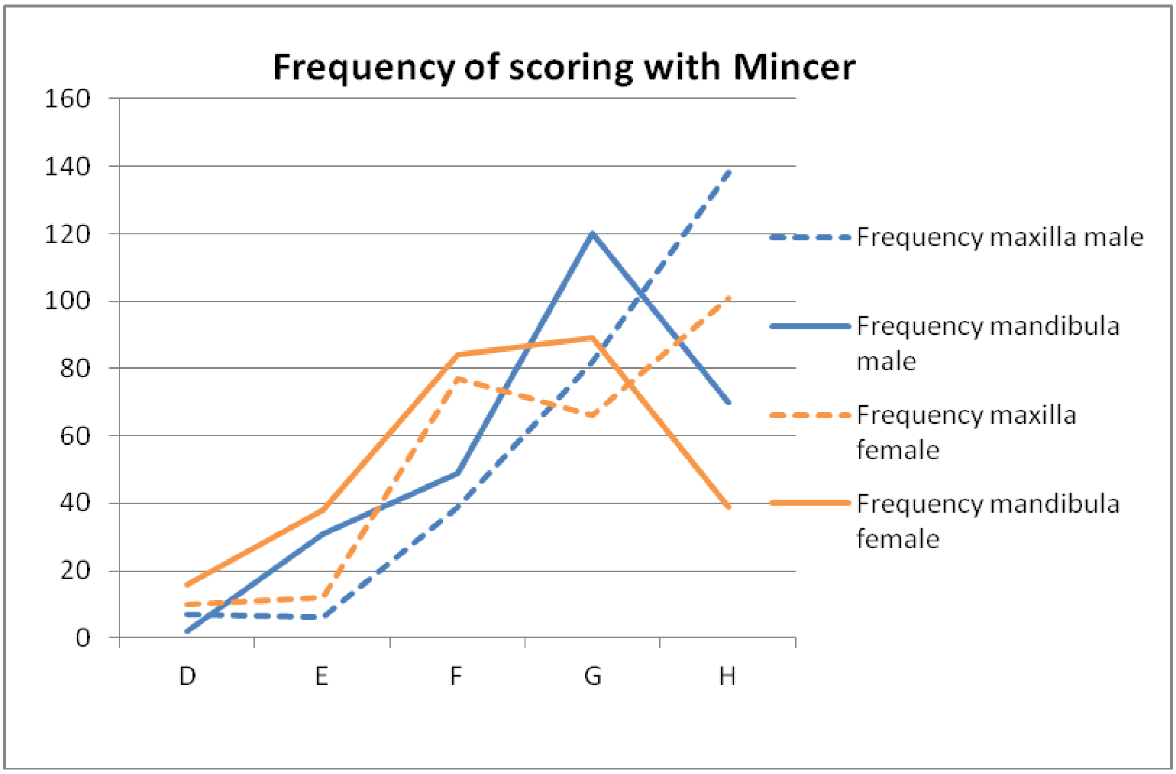

Fig. 7 Frequency of stages, when scoring with Mincer tables of third molar grading (24), when divided in maxilla and mandibular teeth. N (female maxilla/mandibula)= 266/266, N (male maxilla/mandibula)=272/272. There is a higher frequency of later development stages in the maxillary third molars, in both gender, then the mandibular third molar.

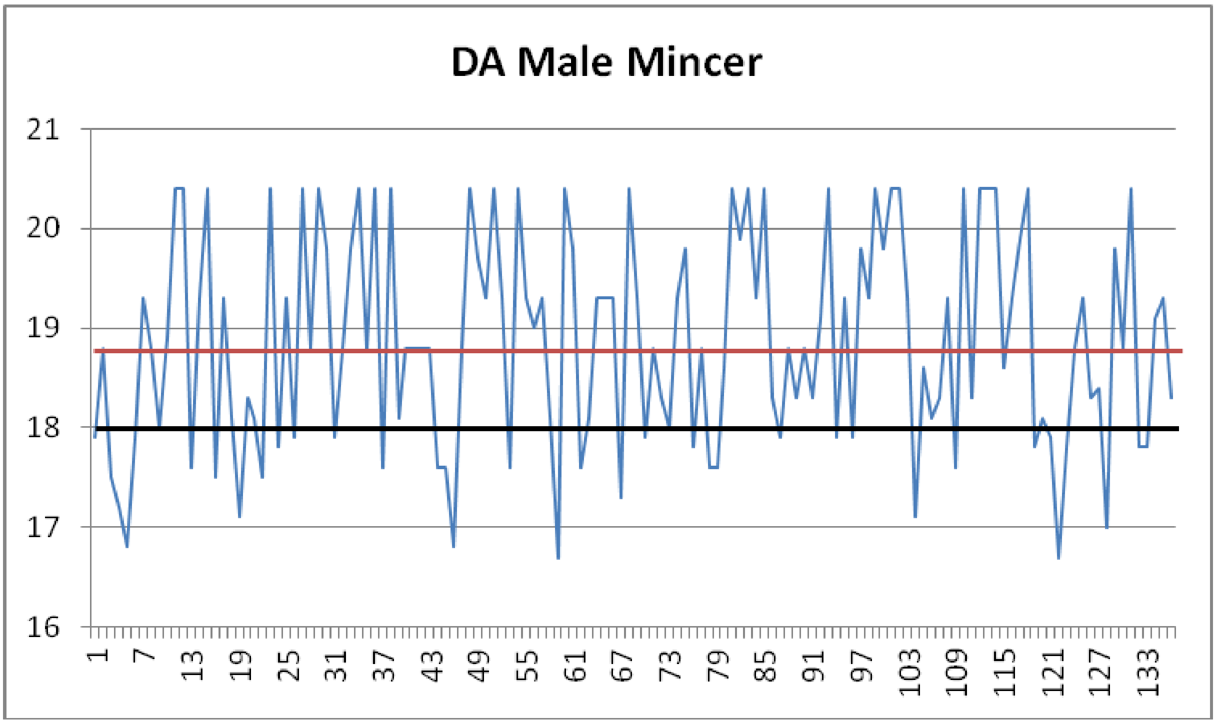

Fig. 8 The diversity of dental age, when scoring with Mincer tables of third molar grading(24). N=136. Average chronological age =18,0 years, average dental age=18,8 age.

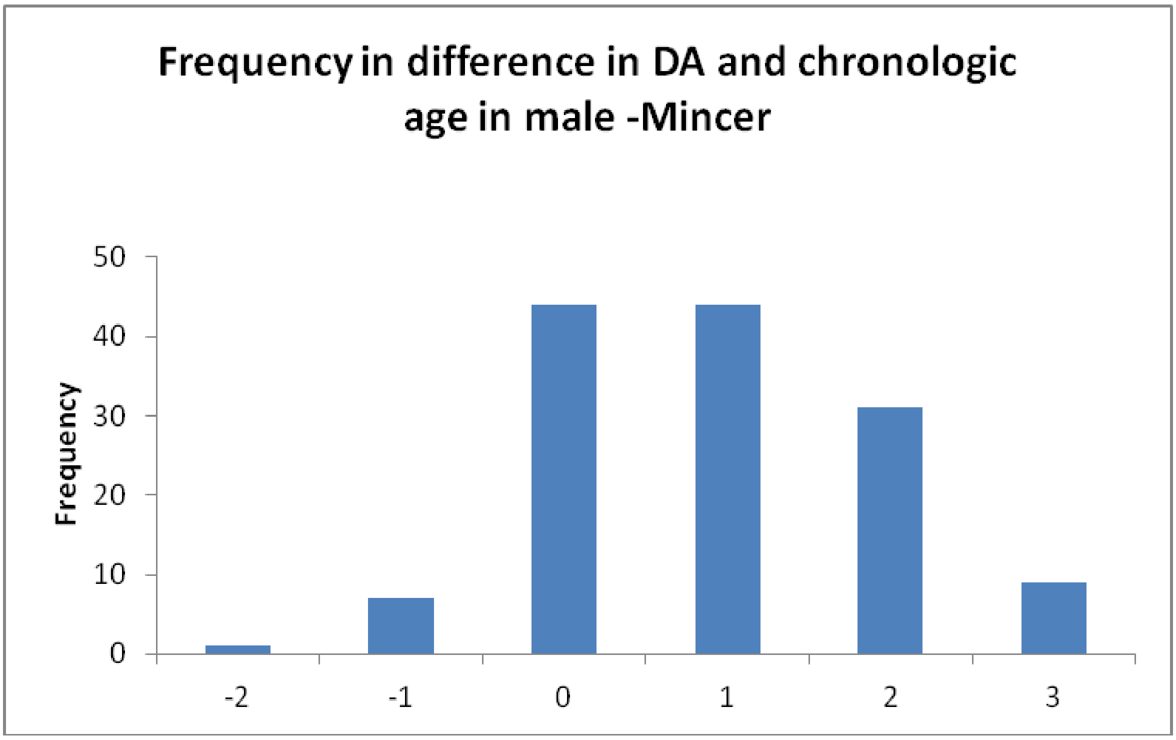

Fig. 9 Frequency in difference in dental age and chronologic age in male, when scoring with Mincer tables of third molar grading (24). N=136. The tables shows there is a higher frequency of overestimating, than underestimating age, for male, when using the Mincer tables.

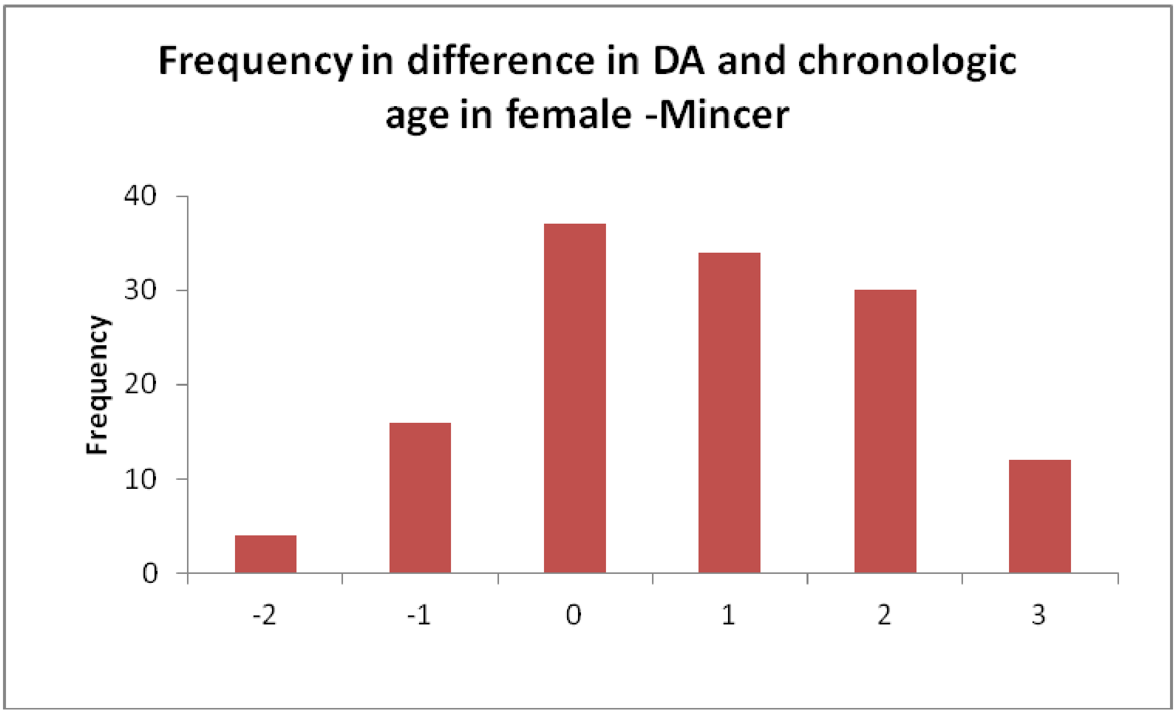

Fig. 10 Frequency in difference in dental age and chronologic age in female, when scoring with Mincer tables of third molar grading (24). N=133. The tables shows there is a slightly higher frequency of overestimating, than underestimating age, for female, when using the Mincer tables.

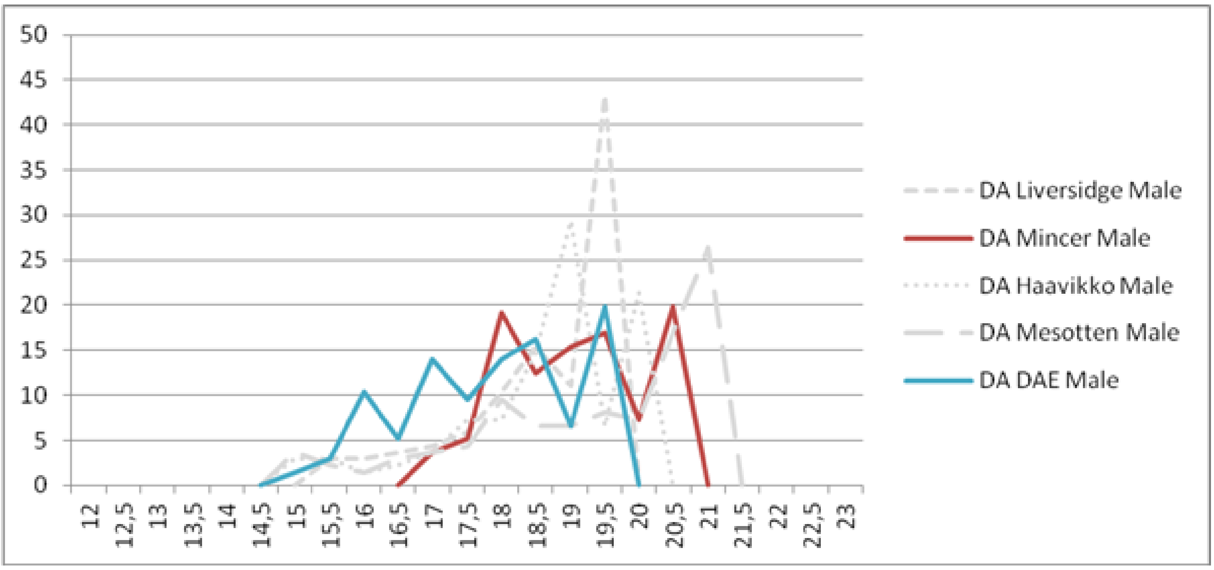

Fig. 11 Frequency of estimated dental age in male, highlighted for grading with Mincer tables (24) and DAE (25). The graphs shows a broad range of estimated dental age, from 14,5 years to 20years for DAE, and 16,5years to 21 years for Mincer. Both scoring tables has several peaks on multiple ages. N=136.

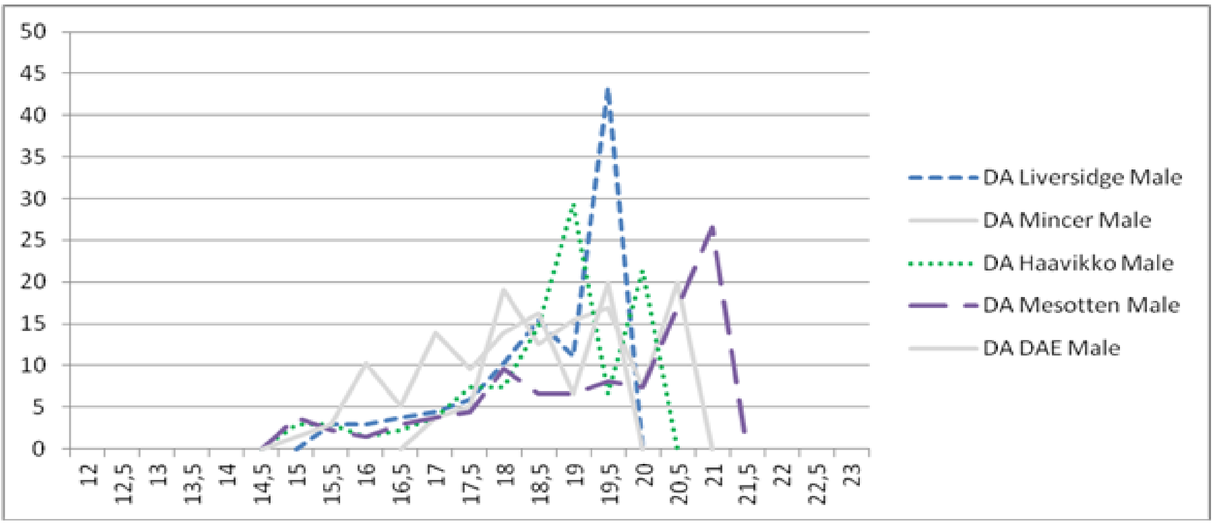

Fig. 12 Frequency of estimated dental age, highlighted for grading with Liversidge tables (23), Haavikko tables (22) and Mesotten tables (21). The graphs shows a broad range of estimated dental age, from 14,5 years up to 21,5 years , with peaks in several different ages. Liversidge has the highest peak, with more than 40 samples, in 19,5 years. N=136.

	Mesotten		Haavikko		Liversidge		Mincer		DAE	
	F	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**
Average DA	18,9	19,1	17,6	18,4	19,0	18,3	18,7	18,8	17,2	17,6
Standard deviation	1,2	1,6	1,7	1,3	1,5	1,1	1,2	1,1	1,2	1,2

Table 1 The average dental age and standard deviation estimated by the five scoring tables of third molar grading, Mesotten tables(21), Haavikko tables (22), Liversidge tables (23), Mincer tables (24) and DAE tables (25). Mesotten has the highest overestimation of dental ages, in both females and males, Haavikko has the estimated dental age closest to exactly 18,0 years. All five tables has 18,0 within +/- 1 standard deviation. N(females) = 133, N(males) = 136.

Inter-observer agreement	Cohens Kappa mandibular and maxillar teeth	Cohens Kappa mandibular teeth	Cohens Kappa maxillar teeth
1. assessment of 20 OPGs by the authors vs. an experienced forensic dentist scoring after Demirjian et al. system	0,624	0,708	0,402
1. assessment of 20 OPGs by the authors vs. an experienced forensic dentist scoring after Moorrees et al. system	0,449	0,540	0,296

Table 2: Inter-observer agreement values. The authors randomly selected 20 OPGs which were assessed at the start of the research and at the end, 5 weeks later. An experienced forensic dentist also assessed the same 20 OPGs. The results were compared by calculating intra-observer agreement and inter-observer agreement using Cohens Kappa regression analysis

Intraobserver	Cohens Kappa mandubular and maxillar teeth	Cohens Kappa mandibular teeth	Cohens Kappa maxillar teeth
1.assessment of 20 OPGs vs. 2. assessment scoring after Demirjian et al. system	0,636	0,654	0,514
1.assessment of 20 OPGs vs. 2. assessment scoring after Moorrees et al. system	0,540	0,470	0,533

Table 3: Intra-observer agreement values, calculated using Cohens Kappa regression analysis. The authors randomly selected 20 OPGs which were assessed at the start of the research and at the end, 5 weeks later.