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Gustafson's Method for Age Determination from Teeth—A Modification for the Use of Dentists in Identification Teams

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ABSTRACT: Gustafson's method for age determination from teeth is based on the evaluation of ground sections of teeth. Six age-associated parameters are evaluated in the ground section and are compared to a regression curve of age versus the age-associated changes. Two of these changes, transparency of radicular dentin and secondary dentin, have the highest correlation with age. The evaluation of these parameters only from thin (0.25-mm) ground sections may lead to an artificially high "secondary dentin value" and "transparent dentin value." These artifacts may be caused by the attempt to include the whole pulp chamber and root canal in a 0.25-mm-thick ground section and by an accidental overgrinding of the apical area of the root, respectively. These artifacts were encountered occasionally even in ground sections prepared by highly trained personnel and became more frequent in ground sections prepared by a person who, though trained, did not use this technique daily. A modification of the data-collecting method is suggested to make possible the use of thick (1.0-mm) ground sections for the evaluation of most of the aging criteria, thereby eliminating the possible inaccuracies in the preparation and evaluation of the thin (0.25-mm) ground sections.

KEY WORDS: odontology, human identification, dentition

Determination of the age of an unknown, decomposed, or burnt corpse is of prime importance in a forensic science examination. When the whole body is available, such determination is based mainly on skeletal changes. However, when only parts of it are found, teeth may be of great help in establishing its age.

For bodies under 18 years of age, estimation of age by teeth can be easily made by comparing radiographs of the jaw with charts of the time course of the development of the dentition [*1*]. Above this age, difficulties are encountered when teeth are used for this purpose. In the past, there have been several intuitive attempts to determine the age of adults according to the condition of the dentition; however, only with the introduction of Gustafson's method were objective criteria used [*2-4*].

Gustafson's method is based on an evaluation of the age of the tooth, which in most cases

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correlates well with the chronologic age of the individual. According to his technique, the investigated tooth is ground thin in its mesial and distal aspects and the ground section used for the determination of several factors: attrition (A), apposition of secondary dentin (S), periodontal condition (P), translucence of the radicular dentin (T), apposition of cementum (C), and apical resorption (R). The translucence of dentin is determined from 1.0-mm-thick ground sections, while all the other factors are determined from 0.25-mm-thick sections. Although most of these factors have a pathologic basis, they also correlate with age. Gustafson evaluated these factors and gave each of them a point value from 0 to 3. The total of point values of each tooth and the known ages of the individuals from whom the teeth were extracted were used for the construction of a regression curve. This curve was then used to determine the age of unknown bodies examined in forensic science investigations.

Each of the aforementioned factors has a different degree of correlation with age. According to Johanson [5], the correlation of the transparency of dentin with age is the highest, while that of apical resorption is the lowest. He analyzed Gustafson's factors statistically and suggested a system in which the numerical value of each factor is multiplied by a constant that expresses its correlation with age.

Johanson was aware of the importance of the accuracy and reproducibility required of the technique by which the different changes in the teeth are recorded. He suggested the use of a 0.25-mm-thick ground section, mounted in a photographic enlarger, for the production of an enlarged accurate tracing or an enlarged photograph from which the different changes are easily and reproducibly evaluated.

Gustafson's method requires specific training of the personnel using the method. This training, by its nature, is a time-consuming procedure. Several investigators have stressed the point that persons who intend to use the method should construct their own regression curve before attempting to determine the age of unknown bodies [4,5] because the interpretation of the criteria is not entirely objective; the personal interpretation used in the cases of unknown bodies should be the same as that used in the construction of the regression curve. Other investigators limited the use of the technique to persons with intensive experience in oral histology. These restrictions limit the possible number of investigators capable of using the method. However, there is a benefit in having the capacity to use this technique in every mass-catastrophe identification team; therefore, a modification of the technique is needed that will make the technique easily taught and reliable when used by identification teams, even when they are not involved in the daily use of the technique.

Several times during the last two decades the need for estimating age by Gustafson's method has arisen in Israel. During the 1973 war, teams trying to identify remains of bodies were confronted with the problem of having only small remains or badly burnt remains, especially in the cases of bodies from destroyed tanks, crashed aircraft, or explosion sites. Therefore, dentists were trained in the use of Gustafson's method of age determination. When Johanson's modification of Gustafson's method was used, we encountered several technical problems affecting the reproducibility of the data collected from the ground sections of the teeth.

The major source of these problems was the use of thin (0.25-mm) ground sections for the evaluation of all the aging factors in the teeth. The use of such thin ground sections is essential for the method of data collection described by Johanson, as he mounts his sections in a photographic enlarger to produce their images on photographic paper. However, when such a thin ground section is prepared even by a trained person, there are two major pitfalls:

1. It is extremely difficult to include in such a thin section the widest diameter of the pulp chamber and root canal; the result sometimes is an artificially narrowed pulp chamber in the ground section.
2. The apical area of the root is narrower than the rest of the tooth and can therefore be ground more rapidly. This can accidentally result in an apical area of the root that is thinner

than the rest of the ground section and therefore more transparent, leading to an artificial, false, high "transparent dentin value" for this tooth.

These two problems become a major obstacle when the person preparing the sections, though trained, is not involved in daily preparations of thin ground sections (such as a dentist in an identification team). Inaccuracy caused by these technical problems affects the two factors that have been shown [5] to have the highest correlation with age, namely the transparent dentin value and the secondary dentin value, and therefore may lead to inaccuracy in age determination.

The purpose of this paper is to demonstrate the disadvantages of using thin (0.25-mm) ground sections for age determination and to suggest a practical way to overcome these problems by using thicker (1.0-mm) ground sections for the evaluation of most of the aging parameters of the tooth.

Method

Examination of the Whole Tooth

The estimation of age is based mainly on the examination of the ground section. However, to obtain additional information and to minimize the chance for misinterpretation of the various factors, as evaluated from the ground sections, it is advisable to start with an examination of the whole intact tooth. Attention should be given to the following factors.

1. *Occlusal Relations*—Every tooth is examined (if possible) in situ, and its occlusal contact and relation to other teeth are registered. The importance of this examination lies in the possibility that a tooth with no antagonist will have a lower attrition value than would be expected from an articulated tooth of the same age. This may also cause low secondary dentin and cementum apposition values. On the other hand, a tooth in an abnormal occlusal contact, which causes its excessive attrition, may give a faulty, high estimation of age.

2. *Caries, Restorations, and Nonvital Teeth*—The teeth are inspected for caries, restorations, or evidence of their being nonvital. Intact teeth are preferred for examination because caries and restorations can result in high secondary dentin and transparency values, while nonvital teeth may have low secondary dentin and transparency values and a high resorption value.

3. *Attrition*—The attrition of the incisal edge of the tooth may be asymmetrical (as in most canines) and, because the ground section is only a slice of the central part of the tooth, the attrition value determined from that section may be misleading. In such asymmetrical cases, therefore, this value should be determined from the whole tooth, before preparation of the section, and this should be referred to when the ground section is evaluated.

4. *Periodontal Condition*—Periodontal changes are evaluated by measuring (on the whole tooth) the distance between the cemento-enamel junction and the epithelial attachment on the buccal and lingual aspects of the tooth. Staining the tooth with hematoxylin facilitates accurate localization of the epithelial attachment [6].

5. *Apical Resorption*—Intensive resorption could easily be detected in a ground section. However, in the case of mild resorption, especially if it is asymmetrical, it is preferable to examine the tooth under a stereomicroscope before sectioning. This way, even slight resorption is not missed. Furthermore, questions as to whether a defect in the apical area of a ground section is resorption or an artifact can be avoided.

Cutting and Grinding Procedures

In forensic dental examinations, situations may be encountered in which only one tooth is available for age determination. Therefore, an effort should be made to use a reliable technique that will minimize the chances of destruction of the investigated material.

The investigated tooth is embedded in a block of plaster so that its buccal surface is exposed. A slice, 1.8 to 2.0 mm thick, is cut buccolingually with a cutting machine [7] having a rotating 0.4-mm-thick Carborundum® disk and a device for holding and moving the block [7]. The slice is cut from the center of the tooth and includes the whole pulp chamber, the root canal, and the apex of the root. This slice is then ground manually on an abrasive paper[4] and a ground section 1.0 mm thick prepared. The 1.0-mm section is used for the determination of the outline of the pulp chamber and for the examination of the transparency of the radicular dentin. The section is then further ground manually on the abrasive paper to a thickness of 0.25 mm and used for examination of the thickness of cementum. In our experience, it is preferable to prepare the 2.0-mm slice in the cutting machine; in cases where no cutting machine is available, it is recommended that the 2-mm slice be prepared by a trained dentist using a cylindrical diamond stone mounted in a high-speed handpiece.

When teeth with curved roots are used, the tooth is first cut in two at the highest convexity of the curved root, and each part is prepared separately.

Evaluation and Registration of Age Changes

Registration of the Outlines of the Tooth—A radiograph of the 1.0-mm ground section is prepared and used for drawing the outlines of the whole tooth, pulp chamber, and root canal. This radiograph is also used for drawing the dentino-enamel junction (Fig. 1a).

Evaluation of the Transparency—The transparency of the radicular dentin is examined and photographed from the 1.0-mm ground section, which is firmly held on a striated background (Fig. 1b). Negative black and white film (Panatomic-X, Eastman Kodak) is used for photography, and the negative is used for registration of the transparency of the dentin (see below).

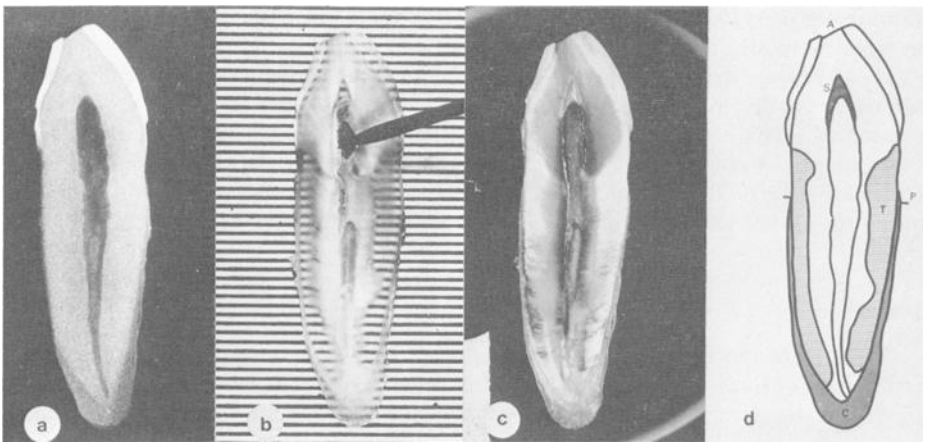

FIG. 1—*Evaluation of the different factors from a lower left central incisor from an individual 66 years old.* (a) *A radiograph of a 1.0-mm-thick ground section, which was used for drawing of the outlines of the tooth, pulp chamber, and root canal and the line of the dentino-enamel junction.* (b) *A 1.0-mm ground section, held on a striated background, revealing the transparency of the root dentin.* (c) *A 0.25-mm ground section photographed with polarized light: the cemento-dentinal junction and the line demarcating the secondary dentin are clearly seen. (In this case the cementum layer is thick, and therefore the cemento-dentinal junction is also seen in Radiograph* a. *This is uncommon in teeth with thinner cementum.)* (d) *A composite drawing that includes all the various factors.*

[4]Waterproof abrasive paper (silicon carbide), grit No. 300 or 500.

Evaluation of the Thickness of Cementum and Secondary Dentin—The 0.25-mm ground section is used to evaluate the thickness of the cementum and secondary dentin. The section is examined and photographed with polarized light while being held between two thin layers of glass (microscope slides) to prevent its bending (as a result of drying). The analyzer is rotated until the cementum and secondary dentin are seen most distinctly (at a rotation angle of 80 to 100 deg between the analyzer and the polarizer). A color transparency is prepared by photographing the section in a darkroom with a color reversal film (Ektachrome, Eastman Kodak). This film is preferred to black and white film because it results in a better contrast (Fig. 1c); however, a black and white negative film can also give reasonable results.

The Composite Drawing—The radiograph of the 1.0-mm ground section is projected onto a sheet of paper with a slide projector that enlarges it twelve times. A drawing is made of the outlines of the whole tooth, the pulp chamber, the root canal, and the line of the dentino-enamel junction. The enlargement facilitates the production of a drawing of high accuracy.

The negative black and white slide of the 1.0-mm section, exhibiting the transparency of the root dentin, is then projected onto the drawing and the boundaries of the transparent dentin are marked. When the slide is projected onto the drawing, the enlargement is carefully adjusted so that the outlines overlap accurately.

Next, the color slide of the 0.25-mm section, which was photographed with polarized light, is projected, and the line of the cemento-dentinal junction is marked. The line separating the secondary dentin from the primary dentin, which is clearly seen in this slide, is drawn as well. In most cases this line is distinct only in the pulp chamber and cannot be seen in the root canal.

The points of the epithelial attachment are marked on the buccal and lingual sides of the tooth, according to the measurements that were made on the whole tooth and were adjusted to the scale of the drawing.

Attrition and apical resorption are shown in the drawing as a result of marking the outline of the tooth, the dentino-enamel junction, and the cemento-dentinal junction. However, in every case, these factors are compared with those evaluated on the whole tooth to avoid misleading artifacts.

The composite drawing (Fig. 1d) is used for the evaluation of attrition, apposition of secondary dentin, transparency of radicular dentin, periodontal condition, apposition of cementum, and apical resorption. Each of the factors is given a point value, according to Johanson's point value system [5]. The sums of the values of each tooth are compared to the regression curve (in the construction of which the same method was used) and an estimation of the age of the individual from whom the tooth was extracted is done.

Discussion

Of the six factors considered in the use of teeth for the determination of age, the dentin transparency value and the secondary dentin value have the highest correlation with age [5, 8]. It is therefore of prime importance to minimize the variability and inaccuracy in the evaluation of these factors.

Johanson [5] used only thin ground sections (0.25 mm) for the registration of all the factors. In our experience, the use of only thin sections may lead in certain instances to some inaccuracies in the data. We therefore prefer the use of thick ground sections (1.0 mm) for evaluating most of the factors.

The pulp chamber and root canal are narrowed by the continuous apposition of dentin. This apposition is physiologic and is increased by such factors as attrition, periodontal disease, and caries [9]. The secondary dentin value is determined by comparing the "present outline" of the pulp chamber and root canal with the outline they had in the past, when the tooth just completed its formation. The "past outline" is determined by the line demarcating

the primary dentin from the secondary, as seen in a thin ground section observed in polarized light [5]. The present outline has been determined by Johanson from the same thin ground section. Our experience has shown that the determination of the present outline of the pulp chamber and root canal from a thin section has certain disadvantages, and a thicker section of 1.0 mm is preferred for this purpose.

In the preparation of a thin ground section there is the possibility that the section will not include the widest diameter of the root canal and pulp chamber. This will result in a narrower present outline of the pulp chamber than actually exists (Fig. 2).

In certain teeth, the narrowed pulp chamber and root canal are curved slightly and an effort to include them in a 0.25-mm ground section may cause artificial narrowing, or even absence, of portions of the pulp chamber and root canal (Fig. 3).

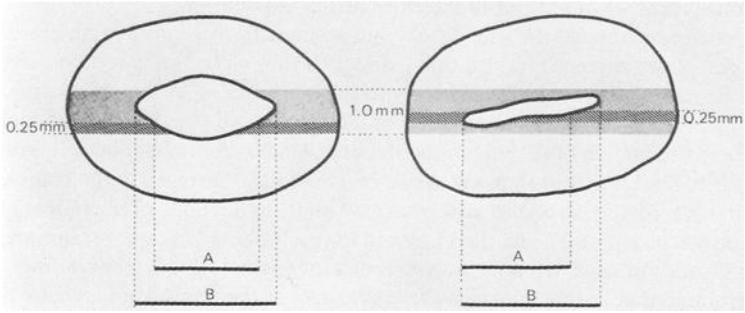

FIG. 2—*Schematic cross section of teeth at the cemento-enamel junction, representing the possibility of an inaccuracy in registration of the width of the pulp chamber from a thin (0.25-mm) ground section.* (A) *Width of the pulp chamber is artificially narrowed in the 0.25-mm ground section.* (B) *Width of the pulp chamber in a 1.0-mm ground section. The projections of dentin above and below the widest diameter of the pulp chamber of the tooth on the left will prevent an accurate evaluation of the widest diameter unless a radiograph is used.*

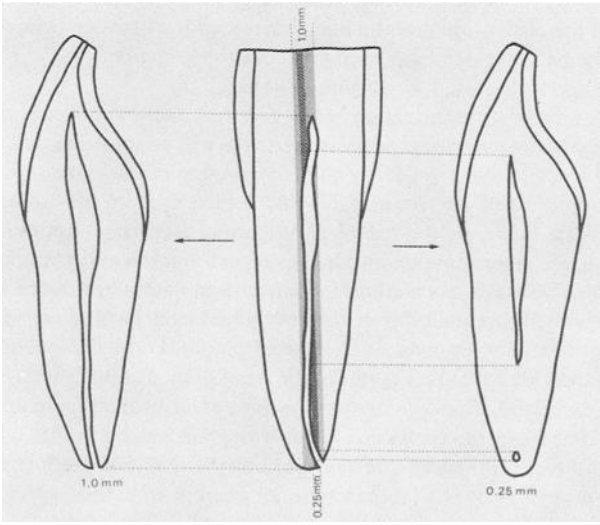

FIG. 3—*Schematic drawing comparing the outline of a curved pulp chamber and root canal in a 0.25-mm ground section* (right) *and a 1.0-mm ground section* (left) *prepared from the same tooth* (center, mesiodistal section). *The pulp chamber and root canal are artificially narrowed in the 0.25-mm ground section.*

An artificially narrowed pulp chamber will give a false, high secondary dentin value and therefore affect the age determination.

A ground section 1.0 mm thick can, in most cases, include the widest diameter of the whole pulp chamber and root canal. However, it is impossible to evaluate visually or photograph this parameter because it is concealed by the dentin projecting above and below it (Fig. 2). A radiograph of this section provides an accurate image of the outline of the pulp chamber and root canal (Fig. 1a). This outline would not be as clear and distinct if obtained from a radiograph of the whole tooth, especially for teeth with narrow pulp chambers.

The transparency of radicular dentin is the factor that has the highest correlation with age [*5,8,10*] and therefore it is of prime importance to avoid any inaccuracy in this regard. The area of translucent dentin in a ground section depends on the thickness of the section. Thus, a 1.0-mm section that reveals translucence only in its apical area will become almost completely translucent when ground to the thickness of 0.1 mm [*5*].

Johanson recommended the use of 0.25-mm sections for determining the translucence of the dentin. Our experience revealed that using such thin sections has certain disadvantages. Even in the hands of an experienced technician, overgrinding of the apical area can occur because this area is narrower than the rest of the section and thus it is ground more rapidly. An accidental reduction of 0.1 mm in the thickness of a 0.25-mm section will be a reduction of 40% of its thickness and that will result in an artificial increase in the transparent area [*5*]. On the other hand, in a thicker section (1.0 mm), unintended overgrinding of the same magnitude will be only 10% and therefore will have a lesser effect on the transparency value.

While Gustafson used 1.0-mm thick sections for evaluating the transparency of dentin, Johanson stated that in this thickness the boundaries of the translucent area are not distinct enough. He, therefore, used a 0.25-mm section for this purpose. The reason for Johanson's claim for the lack of distinct demarcation of the transparent dentin in the 1.0-mm section lies in his technique of evaluation. He mounted the sections in a photographic enlarger, in which light transmitted through the section was used to produce an image on photographic paper. By this method, he was not able to achieve accurate results with sections thicker than 0.25 mm. In our modified method, the section is examined and photographed while being held on a striated background. This technique enables the use of 1.0-mm sections as the area of transparent dentin is clearly demarcated (Fig. 1b).

The thickness of the cementum and the line of demarcation between primary and secondary dentin could not be accurately evaluated from our thick sections (1.0 mm) and therefore thin sections (0.25 mm) were used for this purpose (Fig. 1c).

The use of photography for registration of the different factors makes it possible to provide each identification team with a set of slides that will enable them to use evaluation criteria as close as possible to those used in the construction of the regression curve. In field work, initial determination of the factors can be done directly from the radiograph (Fig. 1a) and from the sections; however, the use of photography facilitates accurate and objective documentation and age determination and makes reexamination and consultation possible.

Our modification of Gustafson's method for age determination avoids the technical problems that jeopardize the reproducibility of data evaluated from ground sections prepared by trained dentists in identification teams. The use of photographic documentation makes it possible to supply each identification team with a set of photographs from which the regression curve was constructed, thereby facilitating the use of evaluation criteria as close as possible to those used when the regression curve was prepared.

A large number of teeth, prepared and evaluated by the modified method described here, is currently being processed by our laboratory in an attempt to base a regression curve on a group as large as possible.

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