Photogrammetric registration of dental plaque accumulation in vivo

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Using the labial surface of upper anterior laterals for determination, the accumulation of plaque was assessed by means of a stereo-photogrammetric method. The stereoimages were subjected to photogrammetric evaluation, the part of the surface area covered by plaque being given in per cent of the total surface area of the tooth. Plaque extension and plaque topography was studied in young adults with healthy periodontia during a 20 day period of no oral hygiene. At the end of the experimental period, on an average 75 per cent of the surface area was covered by plaque, corresponding to an extension rate of 3.75 per cent per day.

The correlation between plaque values obtained by photogrammetry and various estimates obtained from clinical scoring ranged between $r = 0.66$ and $r = 0.78$. It is concluded that the method introduced is a sensitive means of determining small amounts of plaque and should prove useful for in vivo investigation of plaque growth and plaque suppression, where measurements of high quality is of importance.

Key-words: Oral hygiene; oral photography

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Several methods have been designed for the purpose of measuring plaque depostition on tooth surfaces clinically, from simple dualistic ways of denoting presence - absence to more elaborate systems of classification. The idea of these systems is to express the amount of plaque according to some sort of a numerical scale which may be based on quantitative or qualitative criteria (9, 24). These scaling methods or indices are usually founded upon either the extension of deposits along the tooth surface (10) or their thickness near the gingival margin (26) as the feature to be recorded.

Primarily designed for studies of epidemiological character, these methods have been widely used for clinical and experimental investigations. In experimental studies where small differences are to be expected, however, they will often prove inadequately sensitive. To meet with such difficulties the scale may be divided into more and smaller categories (23). However, as the categories of the scale become smaller, their definition will be more obscure and consequently the reliability of the method reduced.

Therefore, there is a need for more precise tools of evaluation for experimental studies on plaque growth and plaque repression *in vivo*. It is desirable

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that such a method is able to express the amount of plaque in quantitative terms according to a well defined continuous scale. Using photogrammetry data from photographic images can yield such information.

A photographical approach for the purposes of clinical evaluation of tooth cleanliness has been used earlier (1, 7, 12, 16, 19, 20, 21, 22, 27). For obvious reasons the photographical registration techniques are best suited for labial projection of teeth of the anterior region of the jaws, thus offering a partial estimate of the hygiene status of the dentition. A highly selective photographic registration method, using one tooth solely for evaluation, has previously been described in a pilot study (3). The present investigation is a further development of this method for the purpose of quantitative measurements of plaque extension *in vivo*.

The amount of plaque present on a selected tooth surface was registered by photography and subsequently evaluated according to photogrammetric principles. The topography and extension of plaque accumulation was studied in young adults during a three week period of no oral hygiene.

MATERIAL AND METHODS

Ten male students at the School of Dentistry, Stockholm, aged 22–26 years and of good periodontal health, participated in the experiment. One week before start of the experimental period the teeth of the participants were cleaned with respect to plaque and calculus. The experiment implied a withdrawal of all oral hygiene measures for a period of 20 days. Otherwise no restrictions concerning diet or eating habits were given. The participants, who volunteered for the study, were informed of the results of previous studies of the same kind and were thus aware that gingivitis might develop as a consequence of no oral hygiene during the test period.

The amount of plaque was recorded on day 5, 10, 15 and 20 after the start of the experiment and in two ways; by direct clinical scoring and indirectly via photographic recording and evaluation. In both instances plaque material was stained by a 0.2 per cent solution of basic fuchsin. The direct *in situ* scoring was made according to the classification of Greene & Vermillion (10). All tooth surfaces of all teeth except third molars were given a score. After termination of the experiment oral hygiene measures were reinstituted and the gingival status was followed up post experimentally.

In this manner a total mean score (T) was calculated for each individual. In addition, certain partial estimates were made, namely: The mean score of all buccal (i.e. labial and facial) surface scores of the individual. The notation B is used for this group. The mean score of all oral (i.e. lingual and palatal) surface scores of the individual. The notation O is used for this group. The mean score of all proximal (i.e. mesial and distal) surface scores of the individual. The notation P is used for this group. The mean score of all buccal and proximal surface scores of the anteriors of the upper jaw. The notation F is used for this group. The mean score of the buccal and proximal surface scores of the posteriors (premolars and molars) of the upper jaw. The notation S is used for this group.

Notations L and L' refer to clinical estimates of the photodocumented lateral incisor as represented by the buccal score only, and the mean of the buccal and the proximal scores, respectively. Notations CL and C'L' refer to clinical estimates of the contralateral with representation as above.

Statistics

The coefficient of correlation (r) was calculated according to the product-moment correlation method of Pearson (15).

$$r = \frac{\Sigma(X_i - M_x)(Y_i - M_y)}{\sqrt{\Sigma(X_i - M_x)^2 \Sigma (Y_i - M_y)^2}}$$

where X_i, Y_i = mean score of the individual as above
M_x, M_y = sample mean of ten individuals.

The average correlation coefficient (r_m) over the total observation period was calculated from

$$r_m = \sqrt{\frac{\Sigma r_i^2}{n}}$$

where r_i = correlation coefficient for certain time interval and $n = 4$.

It should be noted that B, O and P surface scores as well as F and S segment scores form subsamples of T and are thus primarily associated to various degree with the total mean score. This effect has not been considered in the calculations.

Photogrammetry

Plaque evaluation through photogrammetric analysis was based on photograms of one selected tooth, the lateral incisor of the upper jaw. Colour pictures 24 x 36 mm (Kodak EHB 135) were obtained by means of a camera system consisting of a stereomicroscope provided with two cameras for simultaneous exposure of the object (2, 4).

At the time of exposure the subject was connected to the apparatus by means of a biting plate with an impression of the teeth of the upper and lower jaws. In this way approximately the same outer orientation can be retained from one observation time to another.

Two simultaneous pictures with slightly different position in relation to the object form a stereopair. The photogrammetric evaluation of the stereopairs were performed in a stereoautograph B 9 (Wild). This is a first class instrument in which contour mapping and point coordinate measurements can be done with high quality (12, 17).

When viewing the two pictures of a stereopair in the autograph they will form a three dimensional stereomodel of the object in the instrument. Measurements or mapping is performed with the aid of small measurement points inserted one in each of the two lens systems of the autograph. The two points coincide to a «floating mark» that can be placed on any point in the stereomodel along three perpendicular axes (x, y, z). The movement of the «floating mark» in the x y-plane is then transferred to a drawing table. In this way a drawing representing the orthogonal projection of the stereomodel is obtained.

In the present investigation drawings were performed in the orthogonal projection (scale 10:1) of the circumference of the tooth surface under investigation as well as the countour lines of the stained deposits within this area. The magnitude of the total cicrumscribed area and plaque covered areas were measured by planimetry and the sum of the latter areas was expressed in per cent of the total circumscribed area.

The reliability of the photogrammetric method

The photographical procedure as well as the photogrammetric evaluation procedure suffer from errors. The errors inherent in the camera system are dealt with by Berghagen et al (2) and Bergström & Jonason (4). They are con-

sidered as systematic in this connection and their influence is neglected. Uncertainty remains from (A) the lack of reproducibility of repetetive photography, (B) the drawing procedure in the autograph, and (C) the planimeter measurements.

In the first instance stereopairs of the same individuals from before start and after termination of the experimental period were compared. The precision of this procedure (S_1) was judged from differences between such stereopairs according to

$$S_1 = \sqrt{\frac{\Sigma d_i^2}{2n}}$$

where d_i = difference between stereopairs (drawings or planimetry)
n = number of differences

According to the above formulation repeated drawings of the same stereopair were used to estimate the precision of the drawing procedure (S_2) and, finally, repetetive planimetry of one and the same drawing to estimate the precision of the planimetric measurement (S_3). The following values of the precision were obtained

$S_1 = 1.21$ mm^2 (2 %), $S_2 = 0.39$ mm^2 (0.7 %) and $S_3 = 0.13$ mm^2 (0.2 %)

It is seen that the total error of the photogrammetric method is dominated by the contribution from the photographical registration part (S_1) compared to that of the photogrammetric evaluation part ($S_2 + S_3$).

RESULTS

Plaque topography

The accumulation of plaque material on the tooth surface started along the gingival borderline in the shape of colony-like flecks that very soon confluated to a continuous band. Similar continuous layers of plaque material along the gingival margin were usually present after five days (Fig. 1a). In addition, islets of stainable materia were discernible all over the tooth surface. The plaque frontier (i.e. the incisal borderline) was as a rule irregularly shaped (Fig. 1a).

At the ten day observation the continous layer had broadened and the small flecks had coalesced to larger areas. The thickness of the marginal portion of the layer was increased (Fig. 1b).

After 15 days only few isolated flecks of plaque were still present. The distal and mesial portions of the plaque frontier had moved centripetally from the periphery of the tooth surface and had, in several cases, fused in the centre. Along the gingival margin the plaque layer showed an increasing thickness (Fig. 1c).

After 20 days the frontiers starting at the periphery had fused, forming a borderline usually parallell to the incisal edge (Fig. 1d). The thickness of the marginal plaque layer was considerable, and layers emanating from surfaces of two adjacent teeth frequently met to coalesce interdentally. However, not seldom was plaque on prominent earlier covered areas of the tooth surface seen to be torn off (Fig. 1d).

Extension rate

The part of the tooth surface covered by plaque material was continually increasing with time. At the observation ten days after the start of the experimental period more than on an average 50 per cent of the surface was covered. At the end of the experimental period 20 days after start the part of the tooth

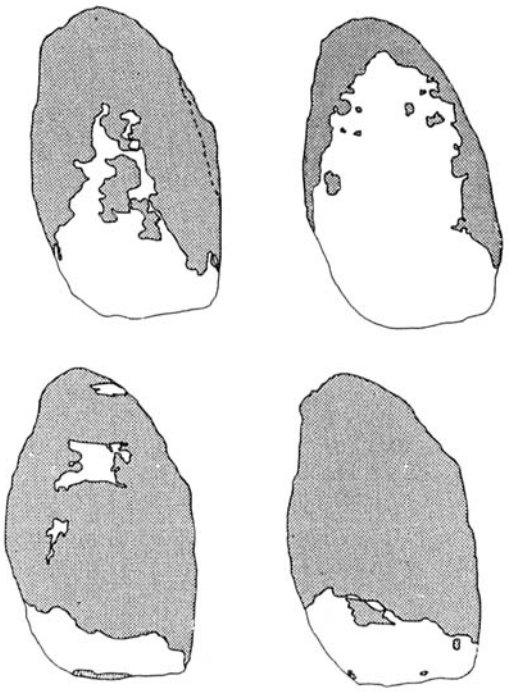

Fig. 1. Mapping of plaque accumulation (dotted areas) based on photogrammetry of the buccal surface of the upper lateral incisor. Subject of rapid accumulation rate.
Plaque coverage at day 5 (upper right).
Plaque coverage at day 10. Dotted line indicates plaque thickness proximally (upper left).
Plaque coverage at day 15 (lower right).
Plaque coverage at day 20. White areas within dotted area indicate plaque that has been worn off (lower left).

surface covered by plaque averaged 75 per cent (Table 1).

The rate with which the deposition of plaque material occurred varied considerably between individuals. The mean deposition rate during all the observation period was 3.75 per cent per day. However, the depostition rate was more enhanced in earlier stages during plaque formation and decreased successively as the surface became covered. During the first five-day period the extension rate was 6.0 per cent per day, during the period 5–10 days 4.6 per cent per day, and during the period 10–15 days 3.2 per cent per day. During the last five-day period an additional 5 per cent of the surface had been covered by plaque corresponding to an extension rate of 1.0 per cent per day.

Table 1. *Photogrammetric determination of the amount of plaque accumulated at different time intervals during period of investigation. Numbers refer to the ratio between plaque covered area and total surface area of the upper lateral incisor*

	DAY 5	DAY 10	DAY 15	DAY 20
PN	0.081	0.303	0.384	0.426
US	0.252	0.473	0.723	0.783
HP	0.532	0.900	0.915	0.859
BG	0.380	0.617	0.861	0.933
AS	0.251	0.282	0.397	0.563
RI	0.281	0.663	0.801	0.831
LW	0.064	0.270	0.362	0.560
GM	0.642	0.831	0.878	0.871
CL	0.211	0.476	0.753	0.658
EB	0.331	0.538	0.849	0.933
Mean	0.303	0.535	0.692	0.742
SD	0.181	0.221	0.222	0.178
SE	0.057	0.070	0.070	0.056

Correlations

The results of the correlation analyses of total mean score, various partial estimates and photogrammetric mensuration are given in Tables 2–7.

When data were treated independently, i.e. without regard to the fact that they are time-related, the correlation coefficients became as shown in Table 2. The closest estimate of total mean score was offered by the proximal scores ($r = 0.95$). The estimate based on scores obtained from the anterior teeth was of the same order as that based on scores from the posterior teeth, $r = 0.84$ and $r = 0.82$ respectively.

The correlations between the photogrammetric measurement and the clinical estimates ranged from $r = 0.52$ to $r = 0.81$. The closest correlations were observed for anterior teeth scores ($r =$

Table 2. *Correlation matrix of correlation coefficients for total period, over all estimation*

	B	O	P	F	S	Photo
T	0.90	0.83	0.95	0.84	0.82	0.76
B		0.68	0.77	0.87	0.87	0.70
O			0.75	0.65	0.56	0.69
P				0.76	0.78	0.68
F					0.80	0.81
S						0.52

T = total mean scores
B = buccal scores
O = oral scores
P = proximal scores
F = buccal and proximal scores of the upper front teeth
S = buccal and proximal scores of the upper premolars and molars

Table 3. *Correlation matrix of correlation coefficients at day five*

	B	O	P	F	S	Photo
T	0.77	0.87	0.96	0.90	0.87	0.69
B		0.46	0.62	0.70	0.80	0.52
O			0.85	0.82	0.58	0.70
P				0.86	0.86	0.62
F					0.74	0.84
S						0.42

T = total mean scores
B = buccal scores
O = oral scores
P = proximal scores
F = buccal and proximal scores of the upper front teeth
S = buccal and proximal scores of the upper premolars and molars

Table 4. *Correlation matrix of correlation coefficients at day ten*

	B	O	P	F	S	Photo
T	0.88	0.86	0.95	0.64	0.77	0.78
B		0.65	0.73	0.79	0.87	0.64
O			0.83	0.34	0.47	0.64
P				0.57	0.72	0.73
F					0.69	0.56
S						0.41

T = total mean scores
B = buccal scores
O = oral scores
P = proximal scores
F = buccal and proximal scores of the upper front teeth
S = buccal and proximal scores of the upper premolars and molars

Table 5. *Correlation matrix of correlation coefficients at day 15*

	B	O	P	F	S	Photo
T	0.95	0.76	0.97	0.92	0.81	0.75
B		0.73	0.87	0.94	0.89	0.69
O			0.70	0.63	0.52	0.60
P				0.90	0.77	0.73
F					0.96	0.70
S						0.51

T = total mean scores
B = buccal scores
O = oral scores
P = proximal scores
F = buccal and proximal scores of the upper front teeth
S = buccal and proximal scores of the upper premolars and molars

Table 6. *Correlation matrix of correlation coefficients at day 20*

	B	O	P	F	S	Photo
T	0.89	0.79	0.92	0.84	0.76	0.66
B		0.70	0.69	0.97	0.95	0.63
O			0.58	0.64	0.52	0.67
P				0.67	0.57	0.55
F					0.93	0.70
S						0.39

T = total mean scores
B = buccal scores
O = oral scores
P = proximal scores
F = buccal and proximal scores of the upper front teeth
S = buccal and proximal scores of the upper premolars and molars

Table 7. *Correlation matrix of correlation coefficients for total period, over all estimation*

	L	CL	L'	C'L'	Photo
T	0.69	0.79	0.82	0.87	0.76
L		0.85	0.86	0.82	0.88
CL			0.82	0.92	0.85
L'				0.90	0.83
C'L'					0.86

T = total mean scores
L = buccal scores of laterals
L' = buccal and proximal scores of laterals
CL = buccal scores of contralaterals
C'L' = buccal and proximal scores of contralaterals

0.81) and for total mean score (r = 0.76). The photogrammetric estimate correlated less closely to the total mean score than any of the clinical partial estimates. When regard was paid to the time aspect, the relative ranking between the various clinical partial estimates concerning their strength to represent the total mean score was mainly the same throughout the observation period. The proximal scores showed the closest correlation, while the oral scores showed the weakest (Tables 3–6). The correlation coefficients for the relationship between the total mean score and photogrammetric evaluation during the period of observation were r = 0.69, 0.78, 0.75 and 0.66 at day 5, 10, 15, and 20 respectively. Likewise, the correlation coefficients for the relationship between scores of the anterior upper teeth and photogrammetry were r = 0.84, 0.56, 0.70, and 0.70 at day 5, 10, 15, and 20 respectively.

The relationships between total mean score, clinical scores of the photo-documented upper laterals, their contralaterals and photogrammetric values are given in Table 7 for the observation period as a whole. The correlation coefficient between total mean score and photo-documented laterals (L) was r = 0.69 when the estimate was derived from buccal scores only, or r = 0.82 when the estimate was derived from buccal plus proximal scores (L^1).

The correlation coefficients of the relationships between clinical scores of the photo-documented lateral and those of the contralateral were r = 0.85 when based on buccal scores only and r = 0.90 when based on buccal plus proximal scores. The correlation between the clinical estimates and the photogrammetric measure of the very same tooth was r = 0.88 when clinical recording was represented by buccal scores only and r = 0.83 when represented by buccal plus proximal scores. The correlation coefficients for the relationships between the photogrammetric measure and the estimate formed by scores of the contralateral as represented similarly were r = 0.85 and r = 0.86 respectively.

Taking the time aspect into consideration the coefficients of correlation between the photogrammetric measure and the clinical scores fell within the range r = 0.72 and r = 0.92. The coefficients of correlation tended to reach higher values at the two intermediate observations than at the observations at start and termination of the observation period. Some of the correlations at day 5 were very weak.

At early stages of plaque formation, the buccal scores formed a very poor estimate of the total mean score (r = 0.31 and r = 0.35). When the estimate was founded upon buccal plus proximal scores the correlation coefficient rose. This was true throughout the observation period.

DISCUSSION

During early stages of plaque formation the morphological characteristics of the accumulated material resembled those of bacterial colonies, as described by Bjørn & Carlsson (5). Plaque colonies were formed immediately close to the gingival margin, but visible parts of the intracrevicular tooth surface was not stained by the dye used. This is interpreted such that plaque material at the gingival border does not primarily invade subgingivally, but grows rather on to the gingival tissue. The presence of subgingival plaque free zones has been observed by others (6, 13).

The surface pattern of plaque extension was characterized by a gradual ingrowth in incisal and centripetal direc-

tions from the gingival margin, as has been described by others (19, 21).

The rate of plaque formation as expressed by its surface extension is not constant. It is more rapid in the early stages of development, while as the surface becomes covered there is a gradual retardation. For the interval 15–20 days the addition of new plaque material is less than 1/5 of that laid down during the 0–5 day interval. This is not surprising, since more incisally located parts of the surface are more «resistant» to accumulation due to mechanical interference with microbial growth. If not for such intervention it is to be assumed that the tooth would be completely covered by a continuous plaque layer within 20 days.

Along with its surface extension the plaque layer also increased in thickness with time. Thickness increase was most pronounced proximally (Fig. 1 b, dotted line), while in prominent areas the plaque layer upon increasing thickness was occasionally torn off (Fig. 1 d).

Although not quantitatively assessed, the thickness of the plaque layer seemed to reach a «steady state». This implies that anatomical and physiological properties of the region in question set limits to plaque thickness growth as well as to plaque extension (15, 16, 27).

When recording plaque photographically it is necessary to use staining agents for visualization. This may be undesirable when studying plaque growth longitudinally as such agents may have an antibacterial potency (5, 16). Present and previous observations (3) give the impression that intermittent staining with a two per cent solution of basic fuchsin does not interfere with plaque accumulation *in vivo*, thus supporting the contention of Goldman et al (8) regarding some other plaque disclosants.

The present method for evaluation of plaque prevalence is highly selective as it is based on the plaque formation capacity of a single surface of a single tooth. In contrast, the surface area selected for projection can be subjected to measurements of known quality according to photogrammetric principles. Since all tooth surfaces are not liable to plaque accumulation to the same degree and to the same rate (16, 19, 27) the question arises whether or not the area used for measurement is representative of the plaque prevalence of the dentition.

According to the present results the anterior upper scores correlated rather well with total mean plaque score ($r = 0.84$), indicating that the anterior region is a good estimate of the plaque disposition of the individual. This is in accordance with previous reports (17) of a linear relationship between photographical recordings of the anterior region and index scores based on all teeth. In the present investigation the correlation between the upper anterior lateral scores and all upper anterior scores was also strong (Table 7). Furthermore, the association between the photogrammetric measure and the anterior scores was also strong, which is in agreement with the data reported by Arnim (1) that plaque growth on the lateral incisor is close to the average of all teeth of the anterior regions. Using the lateral incisor – or any front tooth – for measuring plaque extension also seems justified with regard to the rather high correlation with total plaque score. This coefficient of correlation is of the same order of magnitude as commonly found between different oral hygiene index methods (25).

It is also interesting to note that plaque extension as measured on the upper laterals by the present method during the first ten days of the investigation is very close to that found mor-

phometrically on the lower incisors (20).

When comparison is made between clinical scoring and photogrammetric mensuration, the latter method is more precise and yields a more accurate estimate of reality. The estimate based on clinical scoring of the upper anteriors and the estimate based on photogrammetry run fairly parallell over time (Fig. 2), but the clinical scoring overestimates reality. This overestimation is more pronounced in early stages of plaque development; i.e. when small amounts of plaque are to be recorded. This also seems to be true for the estimate based on proximal scores and for total mean score. On the other hand, as plaque becomes more abundant, the clinical estimates do not discriminate well enough. The five per cent increase from day 15 to day 20 is hardly discerned by the clinical estimates. In other words the clinical scoring is not sensitive enough to record small changes.

The present results show evidence that various samples of surface entities yield different estimates of the plaque level of the dentition. The estimate of plaque prevalence based on oral surfaces only is poorer than that founded on buccal surfaces only. The reason for this difference is that plaque extension on oral surfaces is restricted by the cleansing effect of the tongue and as a consequence scores lower.

Proximal surfaces, on the other hand, form the best estimate of the over all plaque prevalence of the dentition. The reason for this is that they contribute more (by a factor 2) than other surfaces to total plaque mean score and are overrepresented compared to buccal or oral surfaces. Further, proximal surfaces are of a comparatively small size. This means that they are more readily covered by plaque. Using the tooth surface as standard unit – as do present clinical scoring systems – will imply that a small surface is given a higher score than a large one for the same absolute amount of plaque to be recorded.

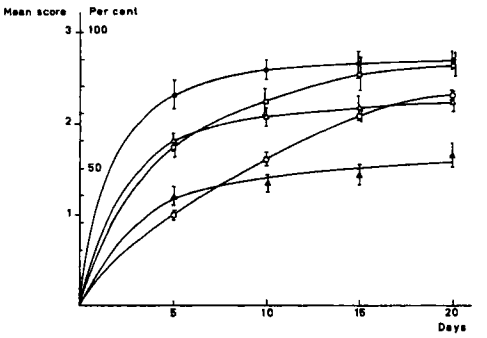

Fig. 2. Plaque accumulaton rate during a 20 day period of no oral hygiene as represented by photogrammetry and clinical scoring.
○—○ Plaque percentage as obtained from photogrammetry of single surface.
△—△ Total mean score.
□—□ Mean score of buccal and proximal scores of the upper anteriors.
●—● Mean score of all proximal scores.
▲—▲ Mean score of all oral scores

By introducing photogrammetric methods for registration of plaque, data of greater exactness can be obtained. Photogrammetric plaque data so far obtained have been expressed in percentages. A development in this respect would be to express the amount of plaque present in absolute quantities such as mm^2 for surface extension or mm^3 for thickness. The prerequisites for such measurements are discussed elsewhere (2).

For summary it can be concluded that the present photogrammetric method for plaque assessment yields a representative measure of the over all dental plaque condition, that it is superior to subjective scoring for registration of small amounts and minute changes and should prove helpful for *in vivo* experiments on plaque growth and plaque inhibition.

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