An investigation of gingival topography in man by means of analytical stereophotogrammetry

II. Changes following periodontal surgery

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With the aid of a stereomicroscope fitted with two cameras, changes in the topography of the gingiva in vivo has been quantitativly evaluated. During the exposures the patient was fixed to the camera system by means of a biting plate. The changes in gingival topography were studied during a 180-day observation period in six cases after mucoperiosteal flap operation and gingivectomy. The gingival topography was evaluated in the direction of photography, the depth, and also in a plane perpendicular to it. The postsurgical swelling was most pronounced after three days. Expressed as volume increase per unit area it amounted on average to 0.6 mm^3 per mm^2. The subsidence of swelling was slower following the flap operation. During the subsequent period of observation (30 to 180 days) a gingival remodelling was observed which, interdentally, involved a coronally directed remigration of the gingival margin by nearly 50 per cent.

Key-words: Healing; gingiva; periodontal disease; photography

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Periodontal surgery is a means of restoring periodontal health. It is indicated when periodontal disease has reached a stage where oral hygiene is rendered difficult or impossible and serves the main functions of eliminating periodontal pockets and of reshaping the gingival tissue to a physiological form. On the other hand all surgery implies traumatization of the tissues involved, including a lesion of the vascular bed, giving rise to — among other things — an inflammatory oedema. Changes in gingival shape and surface contour with regard to time are thus to be expected after periodontal surgery, both as an immediate response to local trauma and also at later stages during the healing process as a consequence of tissue reorganisation and wound remodelling.

Measurements of gingival changes are, however, hard to perform *in vivo* and the magnitude of such changes is consequently not known with any degree of certainty (*Ramfjord, Kerr & Ash*, 1966). Using photogrammetric principles, the shape and changes of shape of an object can be metrically determined from photographs of the object. With the aid of special instruments such metric properties as lengths, areas and volumes may be measured with known, and often high, accuracy. In a previous publication (*Berghagen,*

Bergström & Torlegård, 1968) a photogrammetric method to be used for the objective evaluation of gingival characteristics *in vivo* and its calibration were described. The accuracy and precision of the method were further studied by *Bergström* and *Jonason* (1974) in experiments on test models. The standard error of unit weight was found to be about 0.1 mm.

The object of the present investigation was, by the above method, quantitatively to evaluate changes in gingival form and position that may follow upon surgical treatment of periodontal disease in man. The labial gingiva within a limited region of the upper jaw was selected for measurement and the magnitude of changes was studied both in the direction of photography (sagittal plane) and in a plane perpendicular to it (frontal plane).

MATERIAL AND METHODS

This investigation is based upon six patients, three women and three men, aged 33—47 years, and without any known metabolic disease. The patients had been referred to the Department of Periodontology, Karolinska Institutet, Stockholm, for treatment of periodontitis.

The depth of the periodontal pockets to be treated was 2—3 mm labially and 4—6 mm interdentally. No pronounced mobility of the teeth existed. Prior to surgery all patients were scaled with regard to dental plaque and calculus and instructed in oral hygiene. Oral hygiene was continually checked throughout the period of observation.

Surgery

Two well-known modes of periodontal surgery were used. In three cases (F 1, F 2 and F 3) a mucoperiosteal flap operation was performed and in the other three cases (G 1, G 2 and G 3) a gingivectomy. The periodontal flap technique employed implies a reverse bevel incision through the gingival margin to the alveolar crest near the bottom of the pocket (Fig. 1). The incision was made labially along the gingival margin in the region and a flap containing mucosa and periosteum was separated from the alveolar bone. The flap was extended apically, corresponding to at least the width of the attached gingiva. After elimination of the epithelial lining of the inner aspect of the periodontal pocket and granulation tissue, and after scaling and polishing of root surfaces, the flap was replaced tightly to the alveolar bone and sutured interdentally. The area was covered with an eugenol-containing surgical dressing for one week, after which time the sutures were removed.

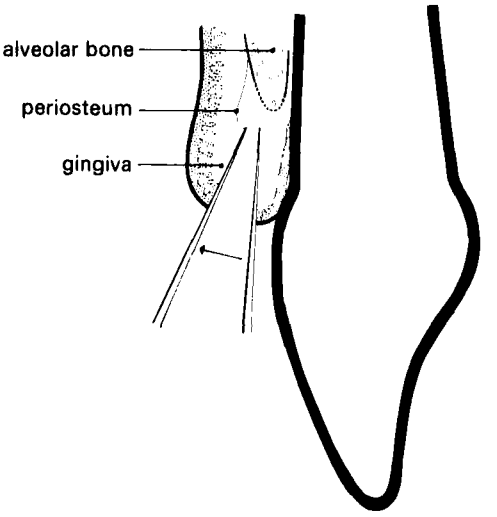

Fig. 1. The flap operation.

In the gingivectomy cases the gingiva was excised to a depth approximately corresponding to the depth of the pocket (Fig. 2). The aim was to place the incision about 1 mm above the bottom of the pocket at an angle of approximately 45°

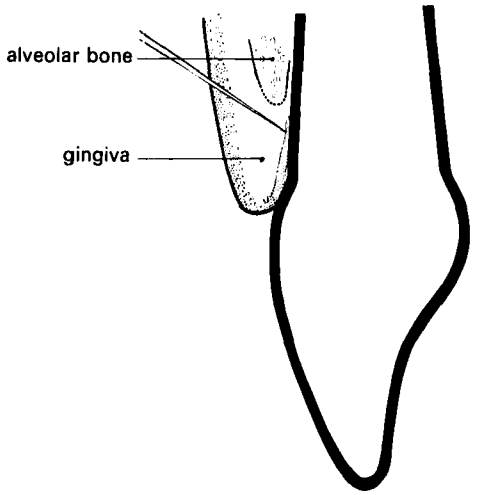

Fig. 2. The gingivectomy.

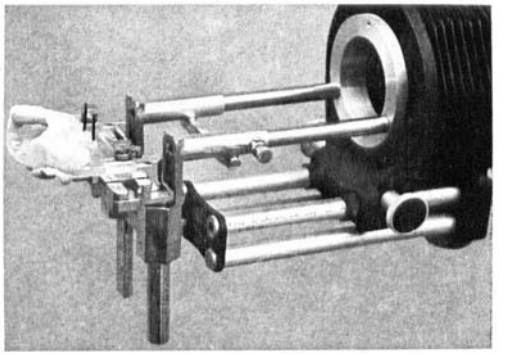

Fig. 3. Bite plate with impression of teeth, mounted on holder. The holder is adjustable in a plane perpendicular to direction of photography. Adjustment in depth is made along the bar.

to the longitudinal axis of the tooth. Following scaling and polishing of root surfaces, the area was covered with an eugenol-containing dressing for one week.

All operations were performed in the upper jaw from the midline to the most distal tooth on one side. The observations refer to the labial aspect of the region between the medial and lateral incisors or between the lateral incisor and the canine.

Photography

A camera system that consisted of a stereomicroscope and two cameras, one for each of the two objective systems of the microscope was used for photography. For further details concerning the apparatus and its calibration reference is made to *Berghagen et al.* (1968). Colour film of format 24 × 36 mm (Kodak EHB—135) was used. Pictures with 1.5 × magnification were obtained.

The region to be studied could be viewed through the oculars during photography and in order to get a similar outer orientation on different occasions, the patient was fixed to the camera system by means of a biting plate (Fig. 3). The biting plate (6 × 4 cm) was furnished with impressions (in acrylic) of the patient's upper and lower teeth. By means of this biting plate and a holder and bar (Fig. 3) the region to be photographed could be repeatedly adjusted into the position chosen relative to the camera system.

The patients were photographed on one or two occasions before and 3, 7, 14, 30 and approximately 60 and 180 days after surgery.

Photogrammetric resolution

The photogrammetric analysis was done in a stereocomparator (Stk 824, Wild) as described previously (*Bergström & Jonason*, 1974).

In each pair of photographs both points on the gingival surface and the so-called reference points, i.e. rather well-defined structures on tooth surfaces which existed in all stereopairs of a given case, were measured. The gingival points chosen were located in a predetermined pattern of equidistant spacing with respect to the reference points, so that they could be repeated in successive stereopairs. Those

gingival points which lay in the y-direction, approximately parallel to the longitudinal axis of the teeth and having a common x-value in the comparator coordinate system, may be said to form a section (Fig. 4). Each such section consisted of 10 to 12 points and the number of sections measured was 6 to 8. The equidistance between points along sections (e_y) was 1.0 mm and between sections (e_x) 2.0 mm in the comparator scale. In this manner sections were measured from midline to midline of the two teeth as shown in Fig. 4, and those sections which are continuous with the tooth surface are denoted dental whereas those which concern the interdental papilla are referred to as interdental.

Determination of volume

On the basis of the finally obtained coordinate values from the calculation of measured points, all sections were »mapped» in the yz-plane. For each section a profile of the gingival surface contour is obtained. Volume changes within the region will cause changes in the appearance of profiles. And a change in a certain profile will define an area (in the yz-plane). When such an area is multiplied by the distance between profiles, the result is a volume.

In order to determine the volume change from the preoperative state, areas formed by changes in profiles (difference areas) were measured with a polar planimeter, and an average for difference areas was found. This average area multiplied by the distance between the two extreme profiles gives a determination of the change in volume $\triangle V_t$ within the region, where the index t denotes time after surgery. Such volumes were calculated at t = 3, 7, 14 and 30 days after surgery.

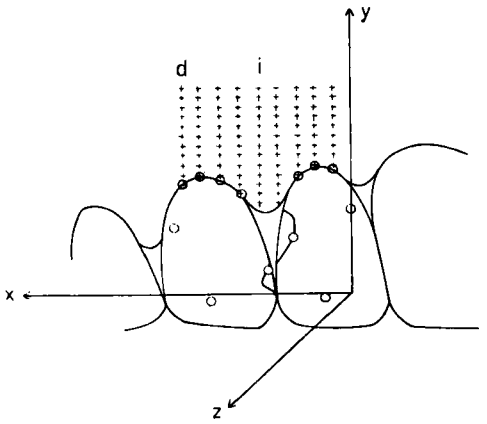

Fig. 4. Region of measurement and definition of three-dimensional axis system in the stereocomparator + = gingival point, ⊕ = dento-gingival »contact» point, o = reference point. d = dental section, i = interdental section.

Determination of the position of the gingival margin

For dental sections, points representing the intersection between gingiva and tooth surface were measured and their coordinates calculated. If such dento-gingival »contact» points are joined together, the course and position of the margin of the gingiva may be obtained. Changes in shape and position with reference to the preoperative state were determined by forming differences between y-co-ordinates for corresponding dento-gingival »contact» points in pre- and postoperative stereopairs using the formula:

$$\triangle Y_t = \frac{\Sigma \quad (y_{t_i} - y_{o_i})}{n} \qquad (1)$$

where y_{t_i} = y-co-ordinate of the »contact» point of the i^{th} profile at time t

y_{o_i} = y-co-ordinate of the »contact» point of the i^{th} profile at time 0

n = number of dental profiles

The value of $\triangle Y_t$ is a measure of the mean change in the y-direction at time t concerning the dental portion of the gingival margin. Regarding the interdental portion differences were formed in a similar manner on the basis of the most coronal point of interdental sections. It is to be noted that, with the direction of the axes of the co-ordinate system defined as in Fig. 4, a positive difference value indicates an apical relocation of the margin and vice versa.

Errors of the method

The errors which affect the final result stem, in part from the photogrammetric method (determination of inner orientation, lens distortion, film shrinkage, lack of planarity), and in part from the object itself (identification, number and distribution of the reference points). For further analysis of the errors pertaining to the method reference is made to *Berghagen et al.* (1968) and *Bergström & Jonason* (1974). In a particular patient series each successive stereomodel was transformed to one and the same reference system, usually that defined by the reference points of the first model. This fitting procedure is called the absolute orientation and the accuracy with which it could be performed is expressed as the standard error of unit weight of absolute orientation (s_o). The number of reference points ranged from three to eight. The average value of standard error of unit weight for each patient series was such that

$$0.036 < s_o < 0.082 \text{ mm}$$

These values apply, strictly, only within the area of the reference points used for absolute orientation. The accuracy of determination of gingival points outside the reference system may be estimated by extrapolation (*Bergström & Jonason*, 1974). Of special interest is the error propagation in the depth direction (z-co-ordinate) with regard to the distance from the reference system in the y-direction. With reference to the distribution of the reference points an extrapolation factor for points within the gingival area under investigation was determined. This factor in all cases was very close to 2.

Under the assumption that the z-co-ordinates of the reference points have a standard error given by the values of s_o above, the standard error of the gingival z-co-ordinates for the present material would lie within the limits

$$0.072 < s_z < 0.164 \text{ mm}$$

Empirically, an estimation of the magnitude of the errors in the gingival points may be made from repeated stereopairs.

Thus, based on differences between z-co-ordinates from corresponding gingival points in stereopairs from two observations prior to, or at the end of, the observation period, the standard deviation in depth of a single measurement of 0.114 mm, was found. For a difference this became 0.161 mm.

RESULTS

Volume changes

The changes in gingival volume within the region under observation and during a thirty-day period after operation are summarized in Table I. The volume differences refer to a surface area limited by the two extreme sections (x = 6.3 to 8.4 mm) and the distance y = 3 mm from the point of intersection of the pre- and third day postoperative profiles as indicated in Fig. 5.

As the area in the xy-plane within

Table I. *Changes in volume* $\triangle V_t$ *(mm³) and mean height* $\triangle H_t$ *(mm) for the region studied at time t (days) after surgery*

Case	$\triangle V_3$	$\triangle H_3$	$\triangle V_7$	$\triangle H_7$	$\triangle V_{14}$	$\triangle H_{14}$	$\triangle V_{30}$	$\triangle H_{30}$
F 1	11.02	0.56	1.65	0.08	—5.45	—0.27	1.93	0.09
F 2	11.93	0.63	7.30	0.38	10.73	0.56	3.75	0.19
F 3	13.57	0.62	7.27	0.33	15.25	0.70	—2.29	—0.10
Mean	12.18	0.60	5.40	0.26	6.84	0.33	1.13	0.06
G 1	21.16	0.88	—4.20	—0.17	1.80	0.07	—4.32	—0.18
G 2	12.65	0.50	4.75	0.18	—2.44	—0.05	—4.75	—0.18
G 3	2.34	0.10	1.82	0.08	0.84	0.03	2.16	0.09
Mean	12.05	0.49	0.79	0.03	0.07	0.02	—2.30	—0.09
Total mean	12.12	0.55	3.10	0.15	3.46	0.18	—0.59	—0.01
S.D.$_k$	5.49	0.23	3.98	0.19	7.26	0.35	3.34	0.15

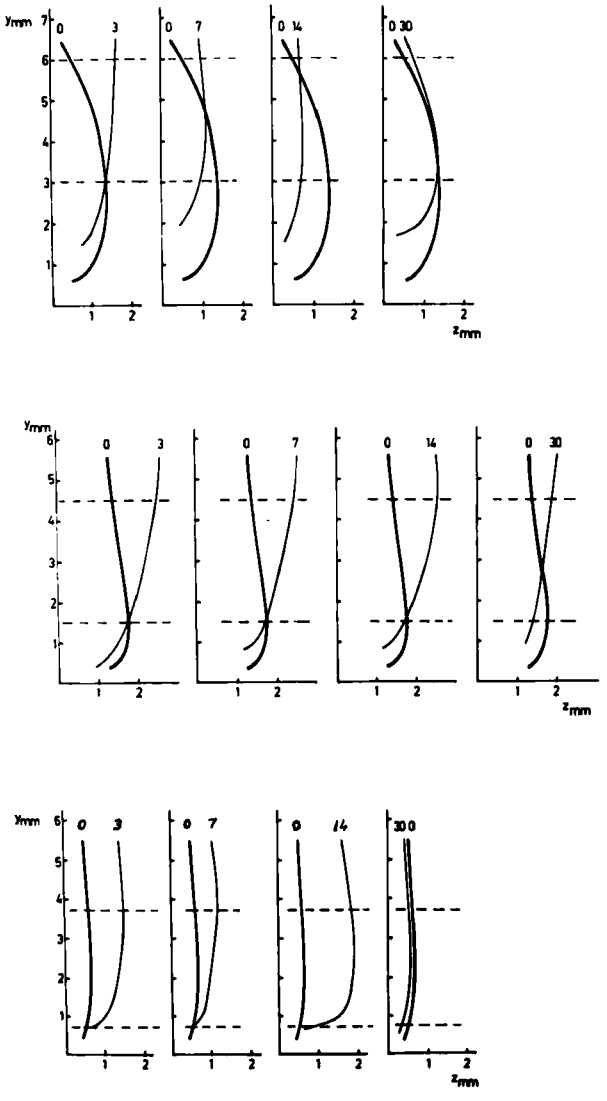

Fig. 5a. Appearance of gingival profiles before (0) and 3, 7, 14 and 30 days after surgery. Changse in volume were calculated on the basis of the area between dashed lines (Y-distance = 3.0 mm). Cases of flap operation. From top: F 1, F 2 and F 3.

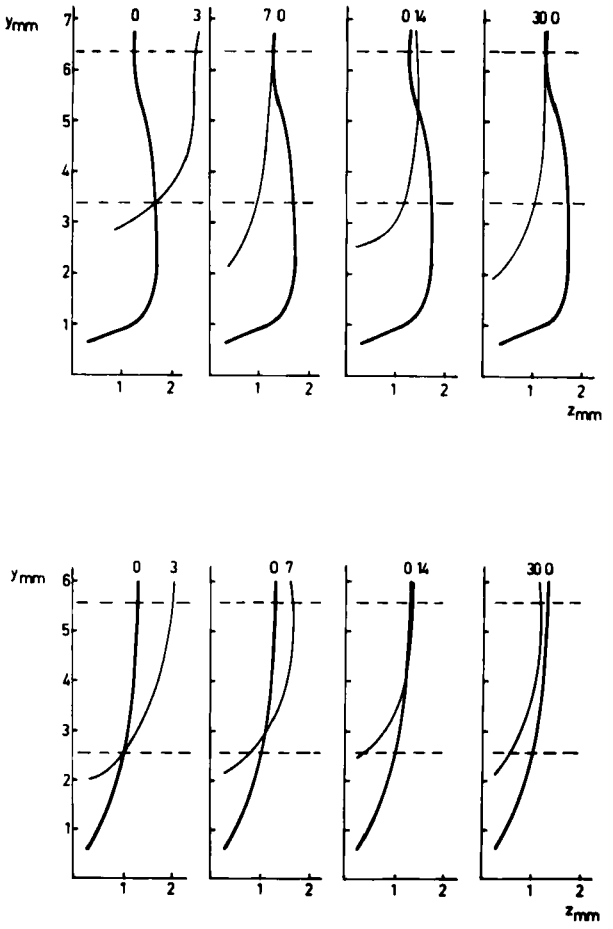

Fig. 5b. Appearance of gingival profiles before (0) and 3, 7, 14 and 30 days after surgery. Changes in volume were calculated on the basis of the area between dashed lines (Y-distance = 3.0 mm). Cases of gingivectomy. From top: G 1 and G 2.

which the volume is calculated is constant, it would suffice to express the changes as a mean shift in the z-direction for this whole area. Values of such an average fluctuation, $\triangle H_t$, of the gingival surface during the period of observation are also given in Table I. The appearances of gingival profiles in the yz-plane corresponding to one selected dental section are illustrated in Fig. 5 for all cases except G 3 (where only small changes occurred).

At the three-day postoperative observation the profiles have higher z-values than before the operation in all cases. The z-distance between the preoperative profile and that of the third postoperative day increases apically in all cases. In quantitative terms the mean volume increase was 12.18 mm^3 and 12.05 mm^3 for the flap-operation cases and the gingivectomy cases respectively.

At the seven-day postoperative observation the profiles of cases F 1, F 3 and G 2 still have increased z-values, although they are now closer to the preoperative level, while F 2 remains at the third-day postoperative level. The mean volume was now 5.41 mm^3 for the flap-operated cases and 2.38 mm^3 for the cases treated by gingivectomy.

Fourteen days after the operation the profiles of cases G 1 and G 2 have re-

attained the preoperative level while cases F 2 and F 3 still remain at a higher level. In their marginal portions the profiles of F 1, G 1 and G 2 have collapsed and the z-values are less than the preoperative level. The mean volume was now 6.86 mm³ and 0.68 mm³ for the flap cases and gingivectomy cases respectively.

At the thirty-day postoperative observation the appearance of the profiles apically approximates the preoperative z-level in all cases except F 2, where they remain slightly elevated. The marginal portion of the profiles is often observed to lie within the preoperative contour. A decrease in mean volume was obtained for the gingivectomy cases (—2.30 mm³). The mean volume for the flap cases was 1.13 mm³.

Changes in position of the gingival margin

The appearance and changes in position of the gingival margin during the period of observation are illustrated in Fig. 6.

Regarding the dental portion the

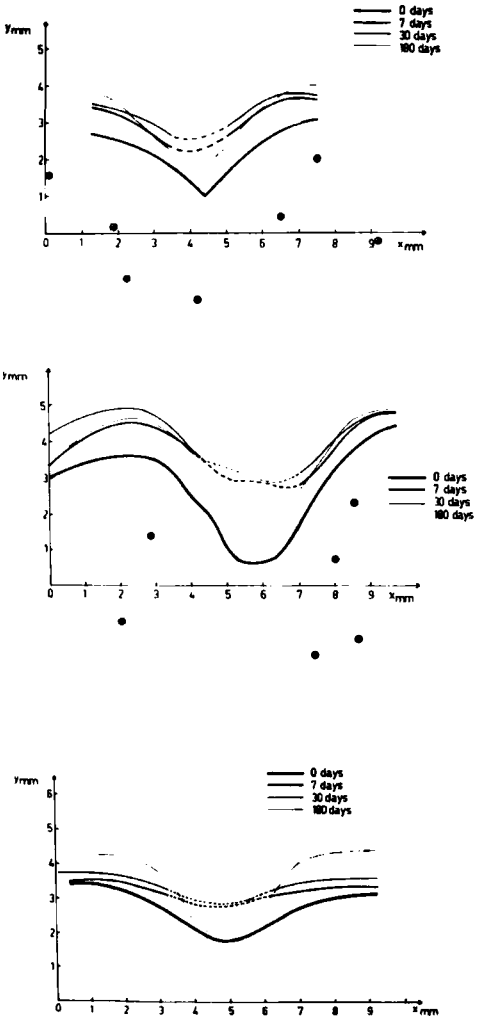

Fig. 6a. Changes in position of the gingival margin during the period of observation. The interdental portion is dashed for post-operative observations. Cases of flap operation. ⊕ = reference point on tooth surface. From top: F 1, F 2 and F 3.

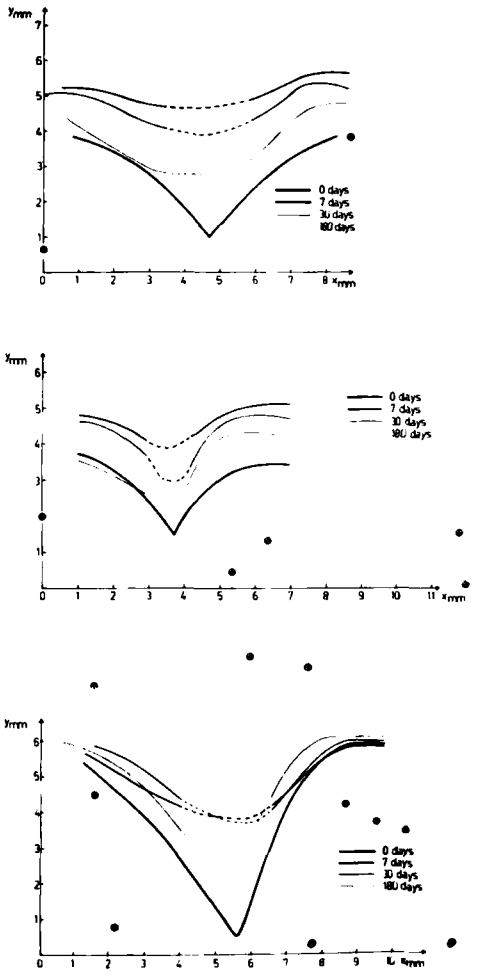

Fig. 6b. Changes in position of the gingival margin during the period of observation. The interdental portion is dashed for postoperative observations. Cases of gingivectomy. ⊕ = reference point on tooth surface. From top: G 1, G 2 and G 3.

changes were calculated according to formula (1) on the basis of the dento-gingival »contact» points. The result is seen from Fig. 7. At the seven-day post-operative observation a shift of the gingival margin in an apical direction is noticed in all cases which roughly corresponds to the amount of gingiva eliminated by surgery, defined by the level of incision or flap reposition. As a mean of all cases the displacement amounted to 0.90 mm. The greatest mean apical displacement is noted thirty days after operation. From that time and throughout the observation period the margin of the dental gingiva remains at a fairly constant level. There is, however, considerable variation between cases; a trend towards a coronal remigration is quite obvious in cases G 1 and G 2.

Concerning the interdental portion of the gingival margin its most apical location occurred seven to thirty days after surgery. After the thirty-day postoperative observation the findings consistently showed a coronal return of the gingival margin in all cases (Table II). The difference between the 30-day and 180-day

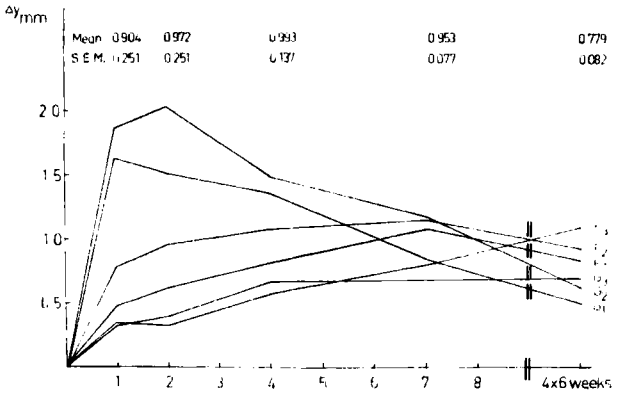

Fig. 7. Changes in position of dental portion of gingival margin during the period of observation. The changes are demonstrated as the mean difference of all dento-gingival »contact» points according to the formulation (1).

Table II. *Gingival interdental recession and regeneration expressed as differences (mm). The comparisons refer to observations prior to (0) and 7, 30 and 180 days after surgery*

Case	Difference (mm) at certain time interval (days)					
	7—0	30—0	180—0	7—30	7—180	30—180
F 1	1.25	1.60	0.90	—0.35	0.35	0.70
F 2	2.25	2.40	1.45	—0.15	0.80	0.95
F 3	1.00	1.10	0.30	—0.10	0.70	0.80
Mean	1.50	1.70	0.88	—0.20	0.62	0.82
G 1	3.65	2.85	1.75	0.80	1.90	1.10
G 2	2.45	1.50	0.75	0.95	1.70	0.75
G 3	3.30	3.20	2.00	0.10	1.30	1.20
Mean	3.13	2.52	1.50	0.61	1.63	1.02
Total mean	2.32	2.11	1.19	0.21	1.12	0.92

values was significant in all cases, and the mean coronal relocation of the interdental gingival margin was 0.92 mm, (S.D. 0.28), which is significant ($t = 8.93$, $P<0.01$).

DISCUSSION

The repair sequence of the periodontal wound after surgery has been described as occuring in three stages (*Wright*, 1968). The initial phase is characterized by the oedema from inflammatory and microvascular changes. Hereafter the tissues will gradually reorganize by reparative processes, and finally there is a maturation and possibly a contraction of the wound.

Described in topographical terms the initial phase of wound healing may imply a volume increase within the operated region due to swelling. According to the present results such a swelling reaction is most pronounced three days after surgery which is in agreement with the findings of *Enger et al.* (1973) on volume changes after local trauma due to phimosis operation, and with those of *Björn et al.* (1954) on swelling after oral surgery. Both reports mention that the swelling reaction reaches its maximum one to three days after the treatment and that after this time the swelling subsides rather fast and usually has completely subsided within one week. This also seems to be true

regarding the gingivectomy cases in the present study, whereas the return to normal after flap operation is somewhat delayed. Such a difference in swelling subsidence rate between these two modes of periodontal surgery was recently observed in a similar patient material by *Bergström* and *Henrikson* (1974). A reason for such retarded swelling subsidence in some cases after flap operation may be that the blood clot between alveolar bone and soft tissue is resorbed rather slowly or that the flap is displaced on removal of the sutures, which may result in the formation of a proliferative granulation tissue between bone and flap. Excessive blood clot formation has been regarded as a factor of disturbance in healing (*Ham & Harris*, 1971). Too early removal of the sutures will reduce the tensile strength of the wound (*Forrester*, 1973) and endanger the readaptation of the flap (*Hiatt et al.*, 1968; *Kon et al.* 1969).

While the topography in the apical part of the wound region gradually reattains an approximately preoperative appearance within thirty days, the remodelling of the wound marginally continues. The surface contour of the wounded area becomes as smooth as or smoother than before the operation, which may be interpreted as a »normalization» towards a physiological appearance, including a decrease of possible presurgical inflammatory enlargement. The trend towards a tissue shrinkage, as indicated by the volumetric determination, may be a consequence of a contraction of the wound or a »healing by scar» as suggested by some authors (*Ratcliff*, 1966; *Stahl et al.*, 1972).

However, a contraction in the sense of an apical movement (a recession) of the gingival margin further than the level of incision or that after replacement of the flap was not observed in the present work. Concerning the interdental gingiva the remodelling of the tissue, on the contrary, involved a coronally directed remigration of the gingival margin by on an average nearly 50 per cent. Indications of such postsurgical events were mentioned by *Zulgar-Nain, Burgess & Zander* (1968). If associated with a concomitant gain in attachment such a regeneration might be interpreted as a positive result of treatment and be attributable to the healing capacity of the periodontium (*Holm-Pedersen & Löe*, 1971). But in combination with a loss or no change of attachment the regeneration would imply a reformation of the pocket and thus suggest a recurrence (*Ramfjord et al.*, 1973). The present investigation provides no answer to these questions since, in order not to disturb healing, pocket depth was not recorded during the postsurgical period.

The present method introduces a nondestructive means of known quality for quantitative evaluation of changes in gingival topography *in vivo* The region selected for the topographical analysis constitutes a unique biological system, consisting of one rather inert component (tooth) and one biologically dynamic component (gingival soft tissue), where the teeth serve as a biological »reference frame».

For further use of the method it would be convenient to calculate the topographic parameter (e.g. the volume) directly from the measured co-ordinates without any graphical plotting and subsequent planimetry. Such calculations are possible by means of integration of certain interpolation functions found from fitting the mathematical model (the mathematical surface) to the measurements. In Fig. 8 is illustrated linear interpolation for gingival volume estimation. First, the area corresponding to each section is obtained

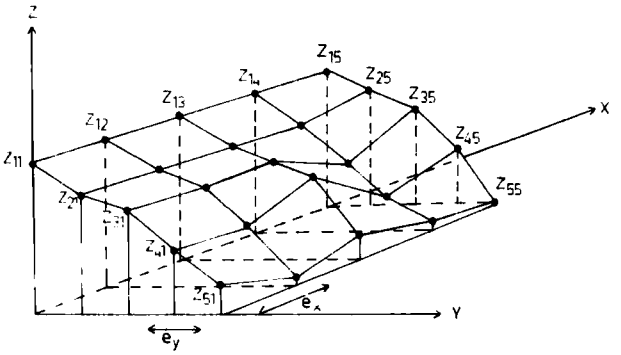

Fig. 8. Linear interpolation applied to a gingival region for determination of gingival volume. e_x and e_y indicate the equidistance in x- and y- direction respectively.

by interpolation and integration within sections, and then the volume is determined by interpolation and integration between sections.

With the notations as in Fig. 8 the volume V for five sections of five points each may be written in matrix form:

$$V = e_x \cdot e_y \cdot A^T Z A \qquad (2)$$

where A^T is a row vector ($\frac{1}{2}$ 1 1 1 $\frac{1}{2}$)
e_x, e_y is the equidistance in x and y respectively

and $Z = \begin{bmatrix} z_{11} & z_{12} & z_{13} & z_{14} & z_{15} \\ z_{21} & \cdot & \cdot & \cdot & \cdot \\ z_{31} & \cdot & \cdot & \cdot & \cdot \\ z_{41} & \cdot & \cdot & \cdot & \cdot \\ z_{51} & \cdot & \cdot & \cdot & z_{55} \end{bmatrix}$

Seven types of interpolation methods* with different degrees of sophistication were tested for calculation of volumes in one case and in the 5 × 5 matrix form mentioned. For further explanation of these methods and their degree of sophistication, reference is made to *Rauhala* (1972). The results are given in Table III together with the volume obtained on the basis of planimetry of corresponding section areas. It is seen that the discrepancies between methods of volume estimation are small. The simplest way, that of linear interpolation (1), represents the average very well and seems to be well suited for the purpose.

Table III. *The gingival volume calculated by interpolation according to various methods of interpolation and integration (1—7) and by planimetry (p)*

Method	Volume (mm^3)
1	7.41
2	7.62
3	7.10
4	7.33
5	7.17
6	7.73
7	7.62
p	7.57
Mean 1—7	7.42

*) 1 linear interpolation
2 » » , adjusted
3 Simpson interpolation
4 Polynomial »
5 Newton »
6 Fourier »
7 » » , adjusted

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