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A 15-year study of osseointegrated implants in the treatment of the edentulous jaw

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ABSTRACT – Osseointegration implies a firm, direct and lasting connection between vital bone and screw-shaped titanium implants of defined finish and geometry – *fixtures*. Thus, there is no interposed tissue between fixture and bone. Osseointegration can only be achieved and maintained by a gentle surgical installation technique, a long healing time and a proper stress distribution when in function.

During a 15-year period (1965–1980), 2768 fixtures were installed in 410 edentulous jaws of 371 consecutive patients. All patients were provided with facultatively removable bridges and were examined at continuous yearly controls.

The surgical and prosthetic technique was developed and evaluated over a pilot period of 5 years. The results of standardized procedures applied on a consecutive clinical material with an observation time of 5–9 years were thought to properly reflect the potential of the method.

In this group, 130 jaws were provided with 895 fixtures, and of these 81% of the maxillary and 91% of the mandibular fixtures remained stable, supporting bridges. In 89% of the maxillary and 100% of the mandibular cases, the bridges were continuously stable. During healing and the first year after connection of the bridge, the mean value for marginal bone loss was 1.5 mm. Thereafter only 0.1 mm was lost annually.

The clinical results achieved with bridges on osseointegrated fixtures fulfill and exceed the demands set by the 1978 Harvard Conference on successful dental implantation procedures.

Edentulousness, inadequately compensated for by dentures, may not only imply impaired oral function and loss of alveolar bone but is also often accompanied by reduced self-confidence.

Efforts^{29,3,49,14,59} have been made to provide edentulous patients with fixed bridges, attached to oral implants (for reviews see IZIKOWITZ²⁹, ADELL *et al.*³, NATIELLA *et al.*⁴⁹, BRÄNEMARK *et al.*¹⁴, SCHNITMAN & SCHULMAN⁴⁹). A great

number of these methods assume the existence of a connective tissue capsule which surrounds the implant and isolates it from the adjacent bone^{42,8,40,66,21,44,54,23}. The presence of such a “pseudo-periodontium” has, however, resulted in inadequate long-term resistance of the peri-implant tissues to mechanical, chemical and microbial trauma^{61,17,45,19,32,65}.

By installation of pure titanium implants of a

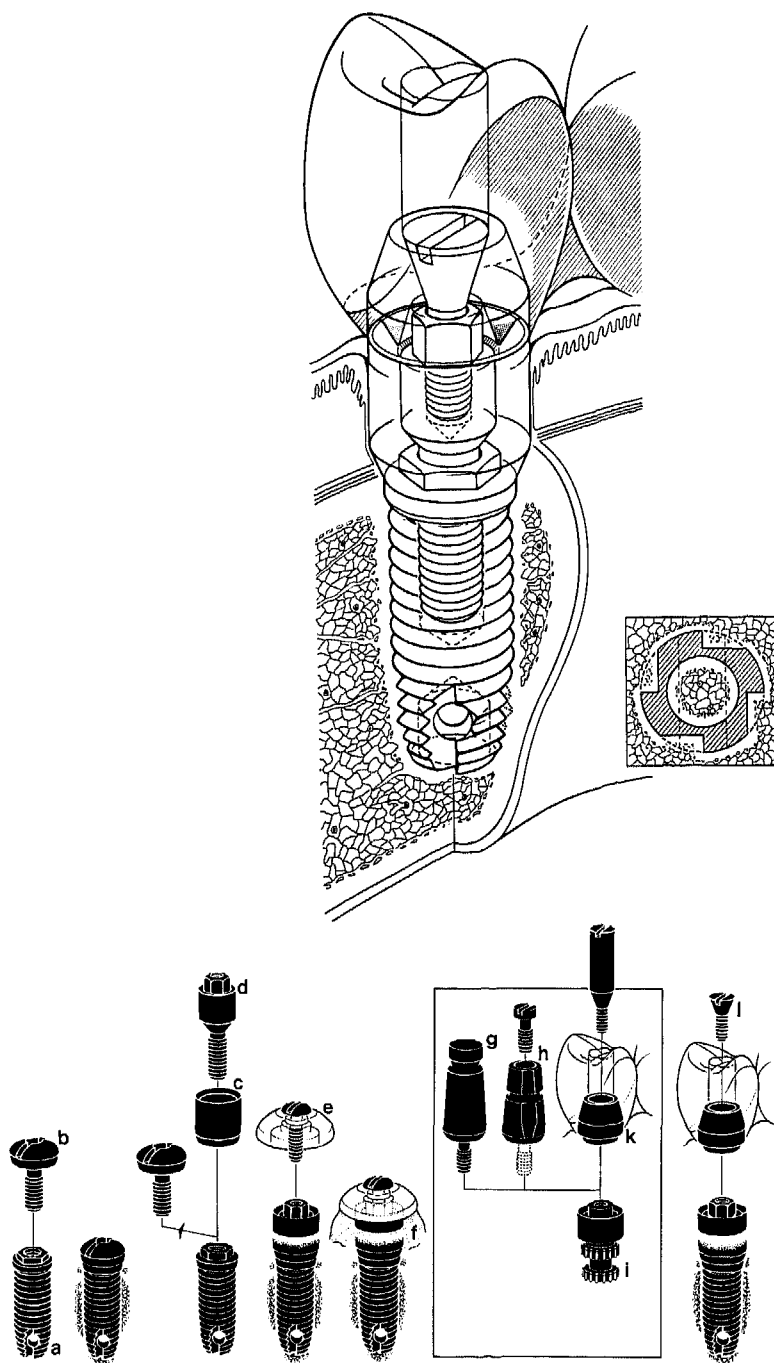


Fig. 1. Mechanical components (fixture, abutment, attachment screws) made of pure titanium and constituting the anchorage unit for the bridge. (a) fixture, (b) cover screw, (c) abutment, (d) centre screw, (e) plastic cap, (f) surgical pack, (g, h, i) copings for model work, (k) gold cylinder, (l) gold screw.

defined finish and geometry – *fixtures* – according to the *osseointegration procedure*^{13,14}, a firm, intimate and lasting connection can be created between the implant and the vital host bone, which remodels in accordance with the masticatory load applied (Fig. 1).

A 10-year follow-up study of bridges on osseointegrated fixtures¹⁴ installed in a consecutive series of patients from the first application of the procedure in a clinical material showed that continuous bridge stability could be achieved in 99% of lower and 76% of upper jaws. After additional clinical procedures the long-term results were 100% bridge stability in lower and 94% in upper jaws.

The effects of bone anchored bridges on the entire masticatory system have been studied by HARALDSON & CARLSSON²⁶ and HARALDSON²⁵. They showed that the patients were restored to a masticatory function equal to or approaching that of dentate persons with the same extension of dentition. Moreover, the patients were subjectively very satisfied with the functional capacity of their fixed bridges. Treatment with bone anchored bridges not only provided oral rehabilitation but was also reflected in rehabilitation of the patient from medical, social and psychiatric points of view^{9,10}.

The purpose of the present paper is to give a summarizing review of material, methods and

results from 15 years clinical use of osseointegrated fixtures in the treatment of the edentulous jaw.

Materials and methods

From July 1965 to September 30th 1980 a total of 2768 fixtures were installed in 191 upper and 219 lower edentulous jaws of 371 patients. In 405 of the 410 operated jaws, bridges were attached to fixtures via mucosa-perforating elements – abutments. In the remaining 5 jaws the treatment was not completed due to death of the patient, or for psychiatric reasons.

In 34 of the patients, bone anchored bridges were placed in both jaws. The sex distribution in the total material was 38% male and 62% female. The mean age at installation of fixtures was 53 years ($s = 11$) with a range of 20 to 77 years. The entire material has been followed *continuously* at one-year intervals.

The evolution of the clinical procedures was divided into three time periods:

1. *Initial period* (July 1965 – March 1968), when experimental knowledge¹³ was introduced to the clinical situation.
2. *Development period* (April 1968 – June 1971), during which certain modifications of the

* s = standard deviation of a single measurement.

Table 1. Total number of fixtures and % distribution of supplementary fixtures of the total number of fixtures

	Upper jaw		Lower jaw	
	Total no.	Supplementary fixtures	Total no.	Supplementary fixtures
Development group	232	22%	195	11%
Routine group I	472	15%	423	9%
Routine group II	277	12%	398	4%
Total	981		1016	
	1997			

The observation time for the development group is 10–15 years, for the routine group I 5–9 years and for the routine group II 1–4 years. These observation times are valid for all following tables which refer to these three project groups.

method were introduced, due to differences between the experimental and the clinical conditions.

3. *Routine period* (July 1971–September 1980), when only minor technical adjustments were accomplished.

In the following, only those cases with an observation time exceeding one year will be reviewed. Results based on observation times less than one year are regarded as uncertain and clinically insignificant. 24 upper jaws have been excluded and have been reviewed separately¹¹ since in these cases the resorption of the jaw bone was so severe that lasting integration could not be obtained in the remaining bone alone. Autologous bone grafts from the iliac crest or the tibial metaphysis were used in combination with osseointegrated fixtures. Thus, of the total material, 1997 fixtures in 146 upper and 172 lower jaws of 284 patients remain for long term evaluation and constitute the material of this paper (Tables 1 and 2).

The reviewed material will be presented as follows.

Development group, consisting of both the initial and development periods together, with an observation time of 10–15 years.

Routine group I, consisting of the routine period with an observation time of 5–9 years.

Routine group II, consisting of the routine period with an observation time of 1–4 years.

The number of fixtures and jaws treated with jaw-bone anchored bridges in the various

observation periods are given in Tables 1 and 2.

The following separate or combined *indications for* treatment with bone anchored bridges on osseointegrated fixtures have been used.

1. Insufficient retention of a denture, generally due to extreme resorption of the alveolar process.
2. Mental inability to accept a denture in cases with technically adequate or inadequate denture retention.
3. Functional disturbances, e.g. severe nausea and vomiting reflexes, caused by a denture.

A preoperative denture period of at least one year was required for a majority of the patients in order to evaluate the rehabilitation effects of treatment with optimally adjusted removable dentures and to provide sufficient time for bone healing after tooth extraction. The mean preoperative denture period for the material was 12 years (range from 1 month to 46 years). In 20 jaws (11 upper and 9 lower), i.e. 6% of the reviewed material, the time between extraction of teeth and installation of a jaw-bone anchored bridge was less than 1 year. These patients, except for 4 cases, belonged to the development group.

In the opposite jaw, 38% of the patients had their own teeth or bridges on natural teeth, 10% wore removable partial dentures and 52% full dentures at the time of fixture installation.

The patients were preoperatively classified into 3 groups according to the degree of alveolar

Table 2. Total number of jaws and % distribution of exchanged bridges

Observation periods	Upper jaw		Lower jaw	
	Total no.	Exchanged bridges	Total no.	Exchanged bridges
Development group	33	61%	32	71%
Routine group I	64	20%	66	9%
Routine group II	49	6%	74	4%
Total	146	318	172	

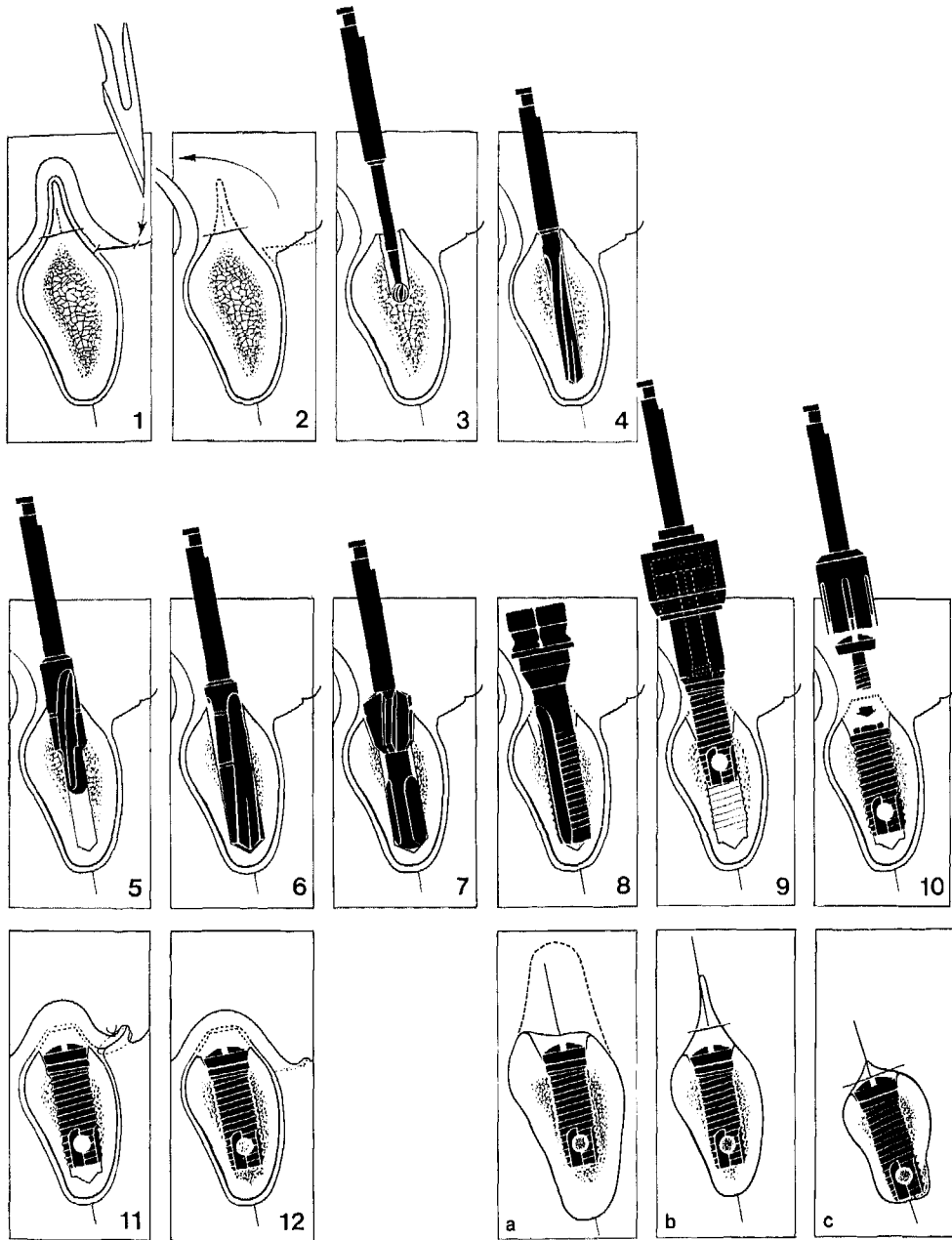


Fig. 2. Different steps at fixture installation in a lower jaw. Fixture sites, usually 6, are prepared in the anterior part of the edentulous mandible between the mental foramina (see also Fig. 4). Steps 3–7 are performed at about 1500 rpm and 8–10 at 15 rpm. (1) incision, (2) reflection of flap, (3) explorative drilling, (4, 5, 6) gradual widening of fixture site, (7) preparation of fixture site entrance, (8) threading of fixture site, (9) installation of fixture, (10) application of cover screw, (11) suturing, (12) condition after healing. (a, b, c) show the anchorage anatomy at moderate, advanced and extreme resorption.

bone resorption, see BRÄNEMARK *et al.*¹⁴. Moderate resorption was found in 10%, ad-

vanced resorption in 80% and extreme resorption in 10% of the total material.

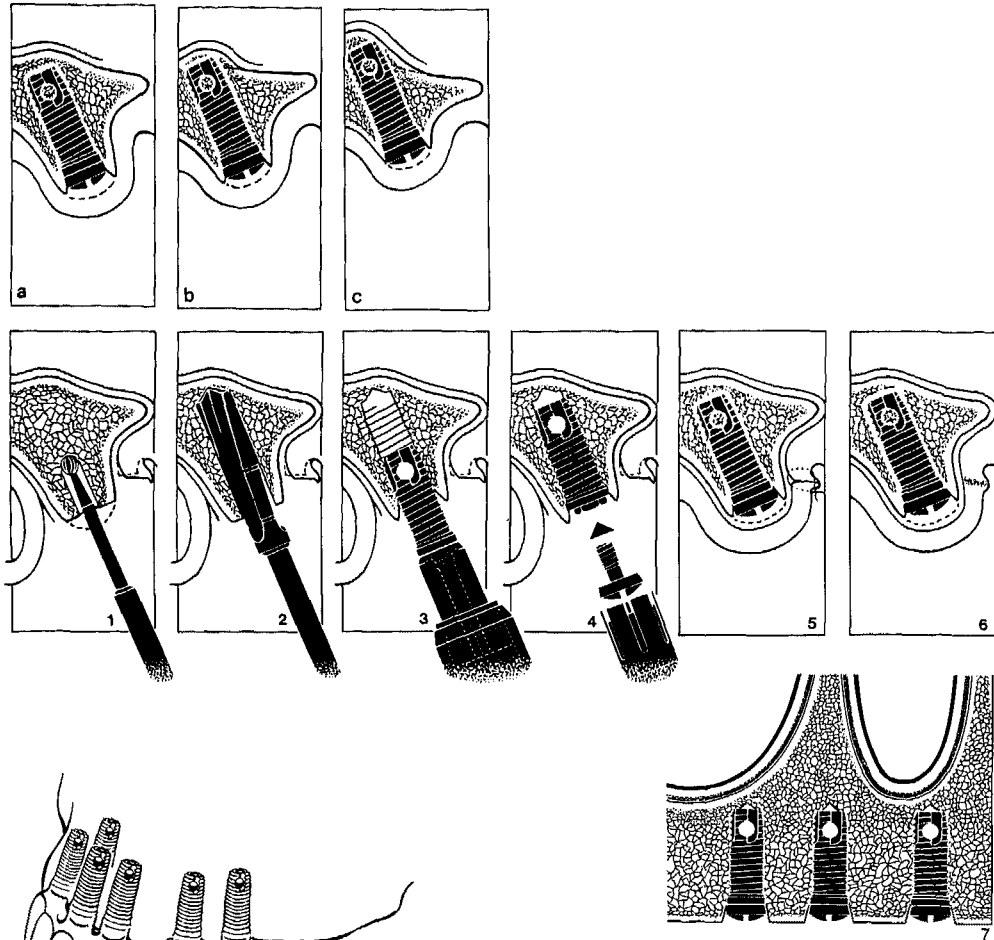


Fig. 3. Different steps at fixture installation in an upper jaw. Fixture sites are prepared in the premolar, canine and incisor regions, anterior to the recesses of the maxillary sinus (see also Fig. 4). (a, b, c) illustrate the anchorage anatomy in the incisor region at moderate, advanced and extreme resorption. (1) and (2) gradual widening of the fixture site, (3) installation of fixture in the threaded site, (4) application of cover screw, (5) suturing of mucoperiosteal flap, (6) condition after healing, (7) topography of fixtures in a case of moderately resorbed jaw bone showing the position of the fixtures in relation to the maxillary sinus and the nasal cavity.

Treatment procedure

A thorough clinical and radiographic examination of the patients was performed as described in an earlier report¹⁴. The patients were accepted for treatment according to previously published guidelines¹⁴ after a joint decision by a team including members of different odontological and medical specialties, especially oral surgery, prosthodontics, oral roentgenographic diagnosis, psychiatry and ENT.

The surgical procedure was performed in two steps, fixture installation and abutment connection. The principles for these operations have been presented earlier¹⁴.

The installation of fixtures comprised the following basic steps (Figs. 2 and 3) performed under premedication and local anaesthesia. The buccal mucoperiosteum was incised horizontally at about half the height of the residual alveolar process. A lingually or palatally pedicled mucoperiosteal flap was raised by sharp dissection close to the bone surface. The dissection was carried out laterally until the neurovascular bundles from the mental foramina or the osseous covering of the anterior parts of the maxillary sinuses could be identified. At the reflection of flaps detachment of periosteum from the bone was kept at a minimum. The number and direction of the fixture sites were established by explorative drilling with a conventional round burr. This procedure also gave information on the character of the cortical and the cancellous bone, respectively. Fibrous, non-mineralized remnants of former extraction alveoli were sometimes found and were either removed or avoided as fixture sites.

6 fixture sites were generally prepared in the region between the mental foramina or – in the upper jaw – between the anterior walls of the maxillary sinuses (Fig. 4). In order to keep a relative parallelism between the fixture sites, preparation was generally started close to the midline and the first fixture site was carefully oriented with regard to the residual bone volume, the opposite jaw and the planned direction of the bridge teeth. A direction indicator was installed into the first site and the remaining fixture sites were prepared accordingly. Specially designed spiral drills of successively increasing dimensions were used at a speed of about 1500 r.p.m. The entrances of the sites were finally adjusted by a special counter-sink procedure, which gave them proper topography with regard to fixtures, fixture holders, cover screws and abutments. The most crucial parts of the preparation included careful threading of the fixture sites and installation of fixtures, both procedures performed at a rotational speed of 10–15 r.p.m. The fixtures were partly self-tapping and had vertical and horizontal canals in their apical parts for bone ingrowth. All bone preparations were carried out with a minimum

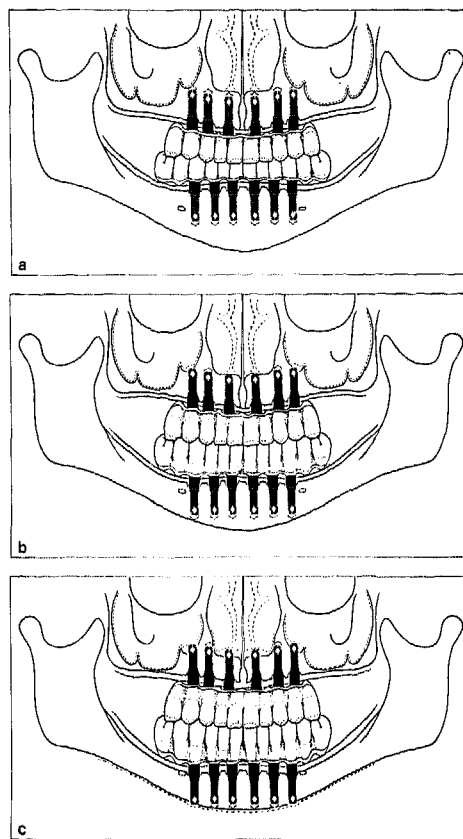


Fig. 4. Fixture topography in 3 typical anatomical situations of alveolar bone resorption is shown in jaws with moderate (a), advanced (b) and extreme (c) preoperative bone resorption.

of torque force and under profuse irrigation with saline at room temperature. Finally, manual control and additional tightening with a ratchet wrench was performed and the fixtures were provided with small cover screws.

The operation was finished with careful readaption of the flap by means of interrupted polyamid mattress 4/0 sutures attempting full periosteal covering of the entire anchorage region. Postoperatively, the patients were asked to bite on gauze rolls for 1 h in order to prevent or reduce hematoma and oedema formation. Liquid and semi-solid food and saline mouth washes were prescribed for the first postoperative week after which the sutures were removed. V-penicillin was given 1 h preoperatively and then regularly for the first 10 postoperative days. 2 weeks after the

operation the denture was relined but no direct fixture loading was allowed for another 3–4 months in the lower and 5–6 months in the upper jaw.

After the healing period an *abutment operation* was performed. At this procedure the cover screws were relocalized (Fig. 5) and exposed by small separate incisions on the top of the crest after which the covering gingiva above each fixture was circularly excised by use of a punch.

The cover screws were removed and abutments attached to the fixtures. The length of the abutments was chosen with regard to the thickness of the mucoperiosteum, i.e. the depth of the canals cut by the punch. A clamp-like instrument was used to grip the outer cylinder in order to prevent the torque force being transferred to the fixture site when tightening the central abutment screw to the fixture. Whenever possible the abutments were made to penetrate through an attached part of the mucosa. When the residual width of the attached mucosa was too narrow or when its localization was not compatible with that of the fixtures, the abutment passages had to be placed in areolar mucosa. Finally the incisions were sutured

on both sides of the abutment and the surfaces of the cut gingival canals were pressed against the outer abutment cylinders. The operation field was covered by a surgical pack for 1 week, retained by healing caps attached to the abutments.

The *prosthetic treatment* started about 2 weeks following the abutment operation. Its details are given in BRÄNEMARK *et al.*¹⁴.

The bridges (Figs. 6 and 7) resembled those used on teeth and were attached to the abutments via screws in vertical canals through the occlusal or lingual surfaces. The pontics and the lingual sections were made of a gold framework while buccal, occlusal and incisal parts were made of an acrylic material. A precise fit between the gold framework and the abutments was the aim. The bridges were extended to include a maximum of 2 teeth distally to the most posterior fixtures in the lower and only 1 tooth in the upper jaws. All bridges were facultatively removable. Great care was taken to design the bridges with sufficient periabutment spaces for oral hygiene measures.

The *oral hygiene program* comprised audiovisual

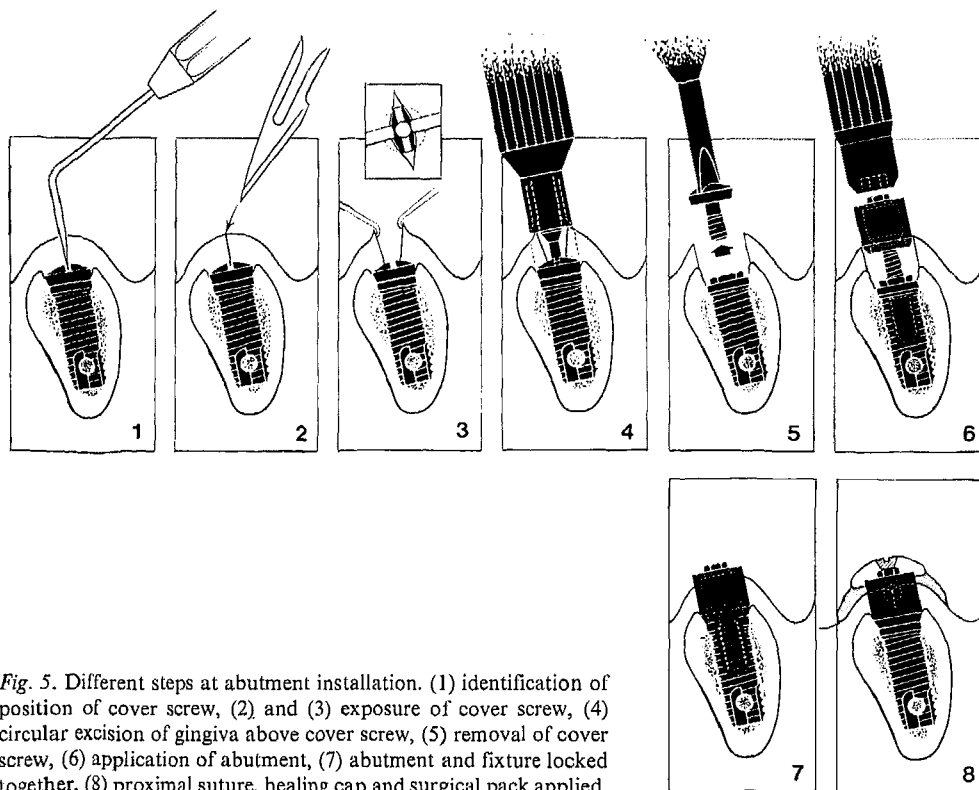


Fig. 5. Different steps at abutment installation. (1) identification of position of cover screw, (2) and (3) exposure of cover screw, (4) circular excision of gingiva above cover screw, (5) removal of cover screw, (6) application of abutment, (7) abutment and fixture locked together, (8) proximal suture, healing cap and surgical pack applied.

information, individual training and printed instructions. At every postoperative registration, the patients were retrained if necessary. In principle the hygiene program resembled that routinely used in periodontology.

Postoperative registrations

Clinical examinations. Regular clinical examinations

were performed on *all* patients at 3-month intervals during the first year after completed prosthetic treatment, and thereafter at least annually. The marginal periabutment tissues were examined regarding possible gingivitis. Occlusion, bridge stability and stress distribution were also checked.

17 consecutive patients from routine group II were subjected to a more detailed investigation of the

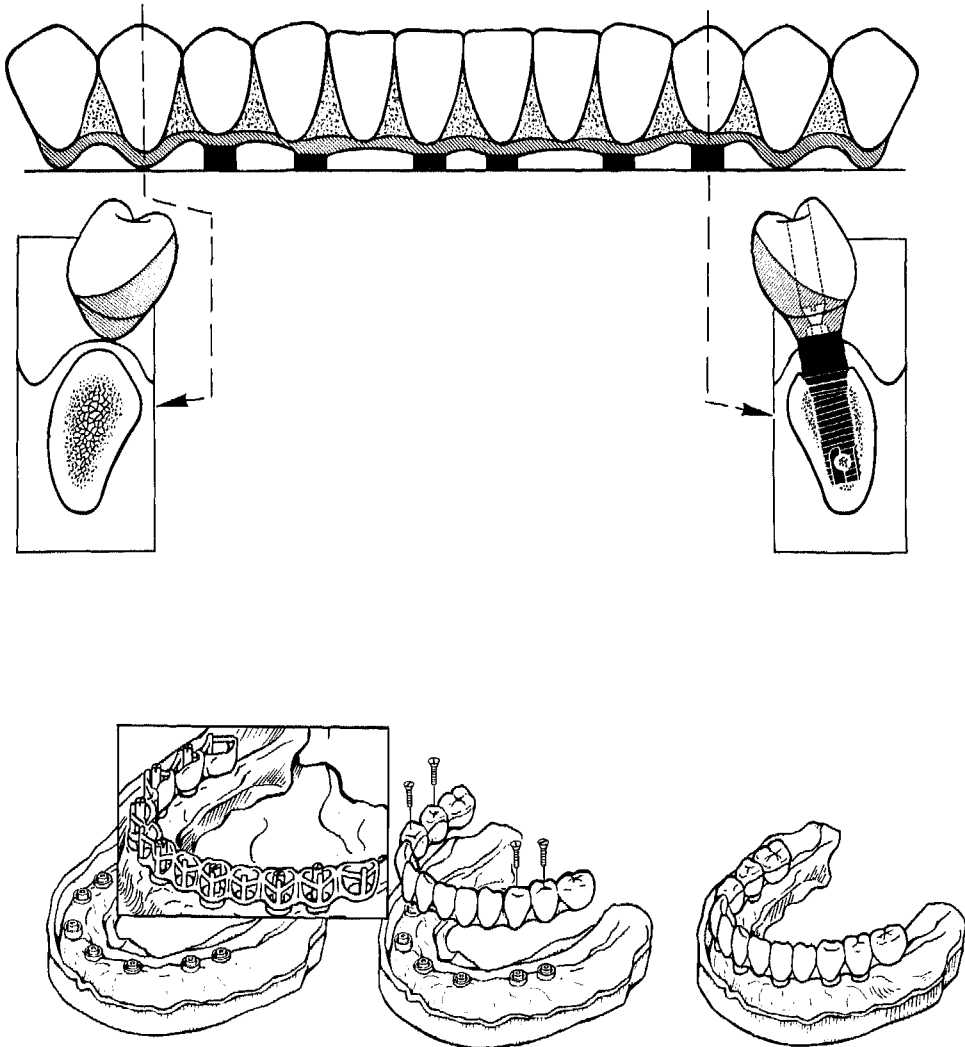


Fig. 6. Bridge design in a lower jaw with pontics and lingual surfaces made in gold and with facings and occlusal surfaces in acrylic. The bridge is provided with pontics only distal to the abutments. The pontics have very small convex surfaces towards the gingiva. The manufacture of the gold framework with acrylic teeth is schematically summarized at 3 stages of production.

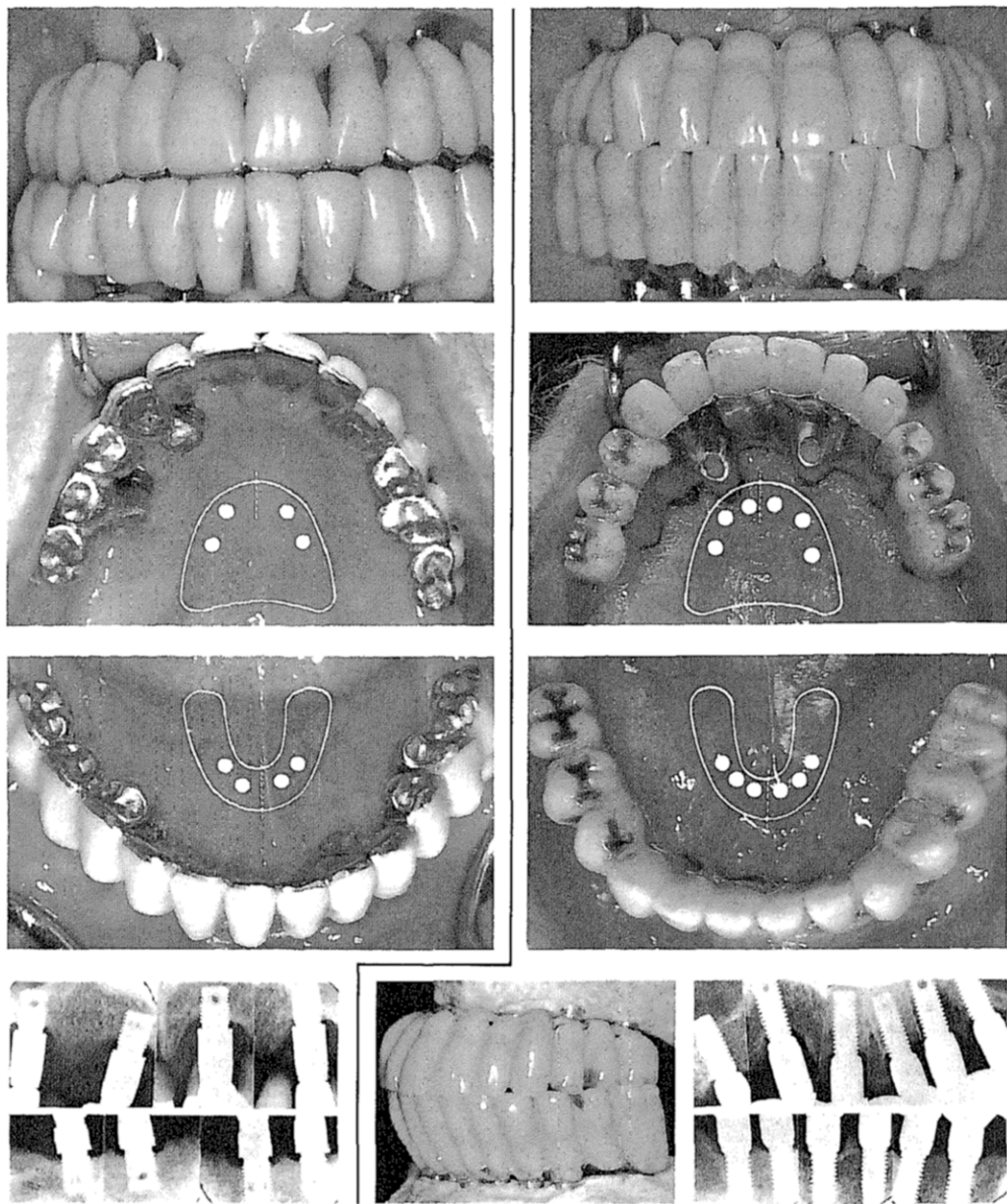


Fig. 7. Reconstruction of 2 cases of edentulous upper and lower jaws. The case to the left, with an observation time of 12 years, was provided with bridges made of gold and porcelain. The yearly loss of anchoring bone amounts to 0.1 mm as revealed at roentgenological examination. The case to the right, with an observation time of 3 years, received bridges consisting of a gold framework and acrylic teeth (*cf.* Fig. 6). The bridges are also shown in the articulator. The yearly loss of anchoring bone amounts to 0.1 mm in this case. The radiograms show the situation after 12 and 3 years, respectively.

marginal tissue. These registrations comprised scoring of plaque and gingival indices, defined as the % number of periabutment quadrants affected. Registration of clinical pocket depth in the same quadrants and of proximal marginal bone height variations were also performed. Altogether 101 fixtures from 7 upper and 10 lower jaws were examined in the manner described. These will be referred to as sample A below (Table 3).

Roentgenological examination. No roentgenograms were taken during the initial healing period¹⁴ to avoid possible negative effects of diagnostic X-rays on the differentiation of healing bone tissue. Radiographic examinations were first performed 1 week after the abutment operation and 6 and 12 months postoperatively. Each fixture was then examined at least once during the following 12-month period. Characteristics of the peri-fixtural bone as well as the condition and mutual fitting of the mechanical components were always considered. For the different time periods and treatment groups the fixtures were analyzed with regard to marginal bone height changes. When 2 or more registrations were performed per year, the mean value of the marginal bone levels was calculated. Loss of marginal bone was measured and related to fixed reference points on each fixture, medially and distally close to the fixture surface (Fig. 8).

During the initial and developmental phases of the project, roentgenograms were taken with a free hand technique aiming at reproducing the fixtures with sharp threadings in the roentgenograms, but without

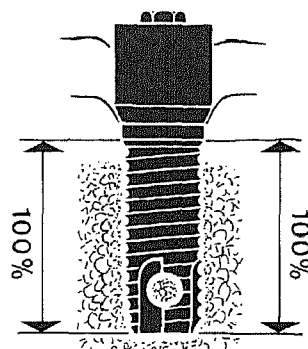


Fig. 8. Diagrammatic illustration of the principle for measuring marginal bone height in radiograms using the fixture as dimensional reference.

an absolute serial identity. The results of measurements of marginal bone height changes in roentgenograms, taken according to the free hand technique, have been published separately^{14,24}. Only those roentgenograms which had good contrast and clearly definable fixture threadings and bone margins were used. In the present study these roentgenograms were re-examined. Thus, the selected roentgenograms fulfilled the requirements of the standardized roentgenographic method described²⁵, with the exception that stereo-pairs were not regularly available.

Table 3. Composition and purpose of samples A, B and C

Sample	Fixtures		Bridges (jaws)		Purpose
	Upper jaw no.	Lower jaw no.	Upper jaw no.	Lower jaw no.	
A					
1 year	42	59	7	10	Analysis of marginal soft tissue reactions
Total		101		17	
B					
Development group	53	27	7	5	Analysis of complications
Routine group I	55	39	8	7	
Routine group II	45	85	7	12	
Total		304		46	
C					
1-10 years					Analysis of marginal bone loss
Total		326			

A standardized method⁵⁵ for serial identical roentgen examination with a strictly parallel technique was developed during the routine part of the project. All roentgenograms taken accordingly were used for measurements of changes in marginal bone heights. The marginal bone levels were defined after stereoscopic examinations.

Consequently the material included 2 parts. One part (development group and early parts of routine group I) was based both on re-examined roentgenograms of the former method and later roentgenograms of the same fixtures according to the latter method. The other part (late parts of routine group I and routine group II) included all fixtures, where marginal bone height changes were followed by the standardized serial identical method.

*Processing of data**. All findings from the clinical and roentgenological registrations constituted the basis for a general computerized follow-up system. Dates of insertion as well as individual fixture, abutment and bridge characteristics were included for all components together with information concerning the opposite jaw.

Comments on methods

Indications for treatment, preoperative examinations, surgical and prosthetic procedures have in all essentials been in agreement with the outlines given by BRÄNEMARK *et al.*¹⁴. It should, however, be stressed that preoperative jaw bone anatomy had no decisive influence on patient selection. The patients rather represented a very wide variety of jaw bone topography ranging from a moderate degree of resorption to a completely resorbed alveolar process.

The difficulties in recalling patients, residing all over the country, at strict intervals for such a long period as that covered by the present paper are obvious. Despite these obstacles it was possible to recall every patient for annual examination, only a few yearly controls being missed due to illness of the patients.

Cases could appear where osseointegration of single fixtures was not achieved or was later lost. Due to the advantage of using separate fixtures,

supplementary installations could be performed when required to maintain bridge stability. The patient continued to wear a stable functioning bridge, while the supplementary fixture was being integrated. After connection of the abutment, the bridge had to be adjusted accordingly or a new bridge manufactured.

To enable evaluation of marginal bone height changes, the roentgenograms should meet the technical demands delineated above, the patients should return at regular intervals and the clinical data should be properly documented. Parts of the material did not meet all these criteria and could therefore not be completely analyzed. Registrations of marginal bone levels were performed at varying intervals until the introduction of the standardized roentgenographic method in the development group and the early stages of routine group I.

The roentgenographic examination of patients with osseointegrated fixtures entailed distinct advantages compared with that of the dentate patient. The presence of built-in measuring elements – the titanium fixtures – of known length and topography and with sharp threadings provided dimensional references for measurement of the marginal bone height.

The necessity of an inter-disciplinary approach between the medical and odontological specialities involved has been clearly demonstrated during the continuing clinical development of the osseointegration method.

Results

Anchorage function

The anchorage function depends on both

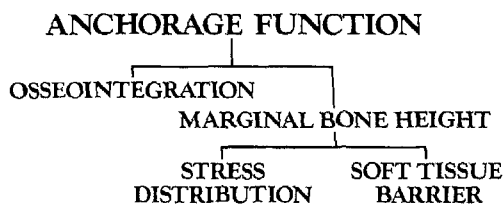


Fig. 9. Principle combination of factors determining anchorage function.

* The handling of numerical data of our computerized registration system by instruction nurse Barbro Svensson and senior system programmer Matz Engström is gratefully acknowledged.

persisting *osseointegration* and maintained *marginal bone height* (Fig. 9).

The anchorage function, defined as the ratio between the number of stable, osseointegrated fixtures supporting a bridge, in relation to the total number of installed fixtures is given for the three observation periods in Table 4. For the routine groups, the anchorage function was 81–88% for maxillary and 91–97% for mandibular fixtures. The majority of fixture losses occurred within the first 3 years after fixture installation, and particularly during the first postoperative year (Table 4). The patients enjoyed continuously stable *bridges* (bridge stability) during the same time intervals in 89–96% of the upper and in 100% of the lower jaws (Table 5).

The number of jaws where supplementary installation of fixtures was required in order to maintain continuous bridge function is presented in Tables 6 and 7. There is a drastic reduction in the requirement for these procedures between the development and the routine groups. Exchange of bridges for this reason has been performed in 61% of the upper and 71% of the lower jaws in the development group. The corresponding figures for routine group I were, 20% for upper and 9% for lower

Table 5. Number and % distribution of jaws with continuously stable bridges

	Upper jaw		Lower jaw	
Development group	26	79%	32	100%
Routine group I	57	89%	66	100%
Routine group II	47	96%	74	100%

jaws and for routine group II, 6% and 4%, respectively (Table 2).

Osseointegration. Clinically stable fixtures were enclosed by a trabecular bone of normal appearance and were in intimate contact with the surrounding bone (Fig. 10) as evaluated at roentgenographic examination. Bone remodeling around the fixtures became – within the limits of the method used – radiographically visible (Figs. 10d–e) in about 10% of the fixture sites after an observation time of 2–3 years, as an increasing perifixtural radiopacity.

Osseointegrated fixtures were almost impossible to remove, i.e. their osseous attachment could not be broken. This was particularly evident in 3 cases where the fixtures had lost more than 2/3 of their marginal bone height. Attempts at extracting the fixtures with appli-

Table 4. Number and % distribution of persisting fixtures

	Upper jaw				Lower jaw		
	Entire period	After 1 year	After 3 years		Entire period	After 1 year	After 3 years
Development group	111 48%	61%	53%		123 63%	79%	74%
Routine group I	383 81%	84%	82%		385 91%	91%	91%
Routine group II	243 88%				388 97%		

Table 6. Number and % distribution of reoperated *upper* jaws; one or several fixtures were installed at each operation

	One operation		Two operations		Three or several operations	
Development group	11	33%	4	12%	5	15%
Routine group I	10	16%	2	3%	1	2%
Routine group II	3	6%	–	–	–	–

cation of a maximum of manual torque force via an extraction forceps demolished the fixtures

but they could not be fractured out of their bone sites.

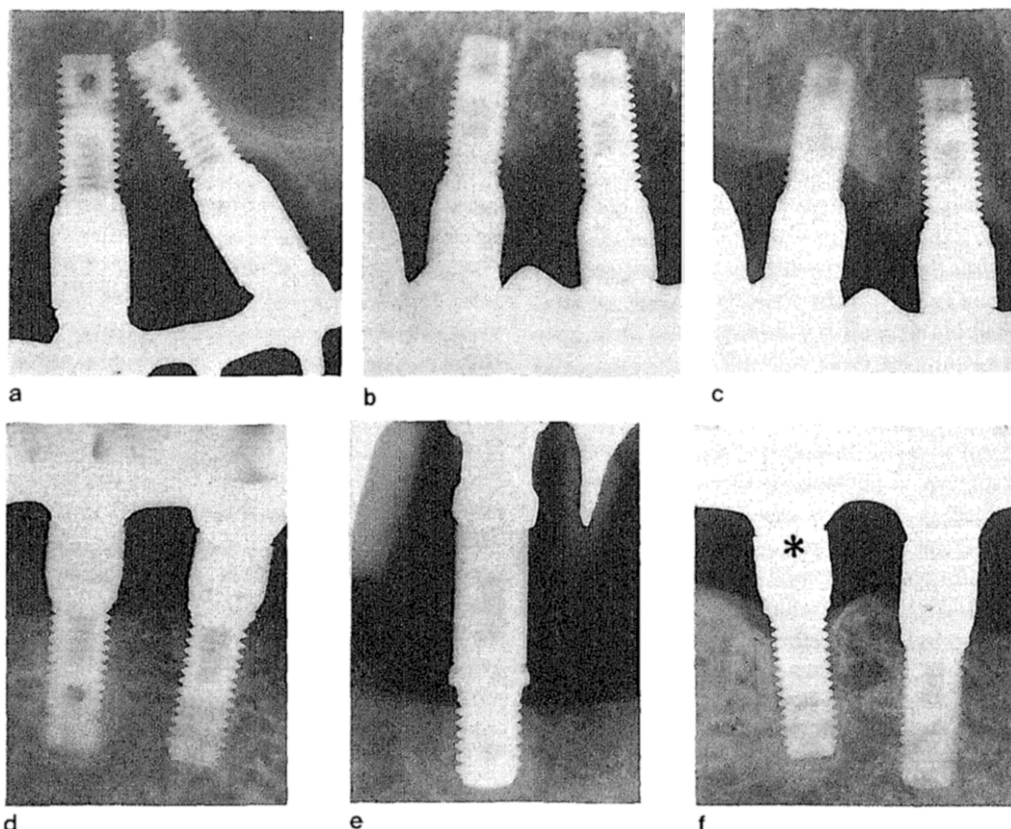
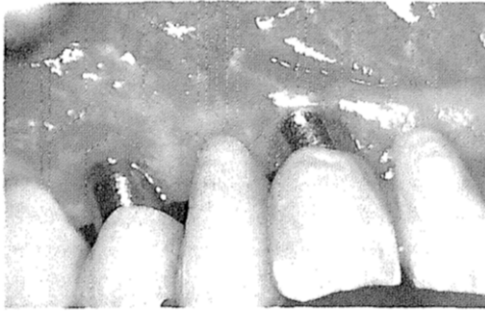
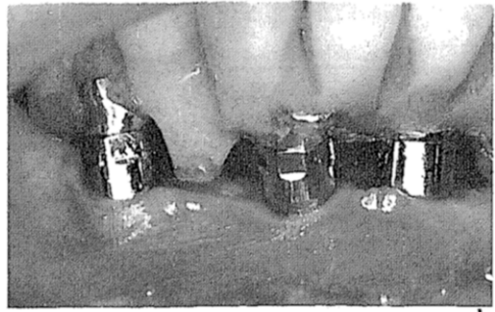


Fig. 10. Roentgenographic analysis of long-term bone reaction at osseointegrated fixtures in completely edentulous jaws. (a) Maxillary fixtures after 6 years of bridge function. Note the close relation of the oblique fixture to the anterior wall of the maxillary sinus. (b); (c) Two maxillary fixtures after 5 (b) and 7 (c) years, respectively, of bridge function. A radiopaque zone can be seen to develop around the fixtures indicating bone tissue remodelling. (d) Two lower jaw fixtures after 7 years of bridge load. (e) Mandibular fixture after 15 years of bridge load showing increased density of anchoring remodelled bone. (f) The roentgenologic technique used enables identification of non-osseointegrated fixtures. The mandibular fixture indicated by * is surrounded by a thin sheath of connective tissue as visualized by a radiolucency. The other fixture in this radiogram remains osseointegrated.

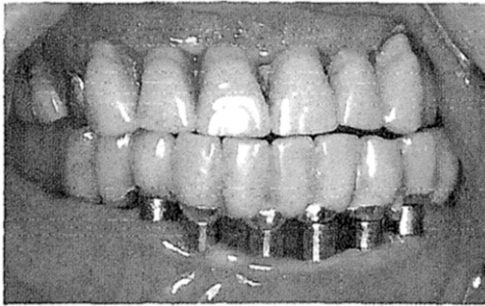
Fig. 12. Clinical status of marginal soft tissues at bridges on osseointegrated fixtures in edentulous jaws: (a) upper jaw after 10 years (original bridge construction – acrylic teeth on chrome-cobalt framework); (b) lower jaw after 10 years (original type of bridge); (c) lower jaw after 3 years (present bridge type – gold framework and acrylic teeth) showing healthy, attached periabutment mucosa; (d) is a detail of the abutment area of the lower jaw shown in (c); (e) lower jaw after 3 years (present type of bridge) with healthy movable periabutment mucosa; (f) is a detail of the abutment area of the lower jaw shown in (e), (f) with bridge attached (g), after removal of bridge (h), after removal of abutment to visualize the condition of the deep mucosa (i).



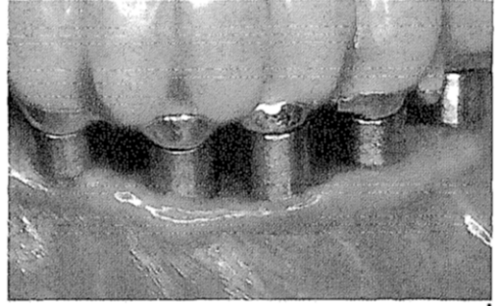
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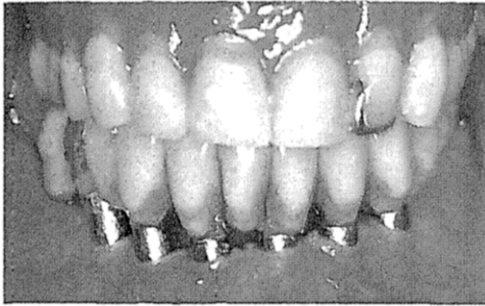
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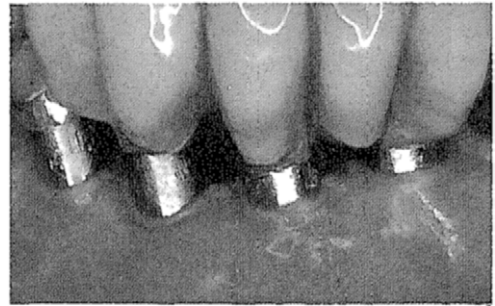
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h



i

Table 7. Number and % distribution of reoperated lower jaws; one or several fixtures were installed at each operation

	One operation		Two operations		Three or several operations	
Development group	12	38%	9	28%	2	6%
Routine group I	2	3%	4	6%	—	—
Routine group II	3	4%	—	—	—	—

Connective tissue anchored fixtures, i.e. where osseointegration had not been originally accomplished or had later failed, were clinically more or less mobile and easy to remove either by mere extraction or by a torque movement. Such fixture sites were lined by a thin, generally threaded soft tissue, which could be removed from the bone walls like a cyst capsule. In the roentgenograms it appeared as a thin peri-fixtural radiolucency (Fig. 10f).

Marginal bone height. The marginal bone height depends on both proper *marginal stress distribution* (cf. Introduction) and on adequate function of the *marginal soft tissue* (cf. Fig. 9).

The results of the roentgenological examination of the changes in marginal bone height are presented in Tables 8 and 9 and illustrated in Figs. 10 and 11. Bone loss occurred predominantly during the healing and remodelling

periods, i.e. from fixture installation to the end of the first year after bridge connection and amounted to a mean of 1.2 mm for all groups. The mean yearly decrease in the follow-up period, i.e. after the first year had passed, was 0.1 mm ($s=0.4$) for upper and 0.1 mm ($s=0.8$) for lower jaws in the development group. The

Table 9. Mean annual marginal bone loss (in mm) during follow-up periods

	Upper jaw	Lower jaw
Development group	0.1 ($s=0.4$ $N=179$)	0.1 ($s=0.8$ $N=184$)
Routine group I	0.1 ($s=0.6$ $N=1145$)	0.1 ($s=0.5$ $N=963$)
Routine group II	0.1 ($s=0.6$ $N=69$)	0.1 ($s=0.6$ $N=130$)

s =standard deviation, N =number of observations.

Table 8. Mean marginal bone loss (in mm) during the healing period (from fixture installation to abutment connection) and during the the remodelling period (first year after abutment connection)

	Upper jaw		Lower jaw	
	healing	remodelling	healing	remodelling
Development group	1.2 ($s=0.9$ $N=207$)	0.1 ($s=0.8$ $N=43$)	0.7 ($s=0.9$ $N=147$)	0.1 ($s=0.4$ $N=58$)
Routine group I	1.3 ($s=1.1$ $N=358$)	0.2 ($s=0.9$ $N=153$)	1.0 ($s=1.0$ $N=211$)	0.4 ($s=0.6$ $N=86$)
Routine group II	0.7 ($s=1.0$ $N=431$)	0.6 ($s=0.8$ $N=227$)	0.3 ($s=0.5$ $N=1006$)	0.8 ($s=0.8$ $N=358$)

s =standard deviation, N =number of observations.

When interpreting these figures it should be emphasized that there is a great variation in the duration of the healing time for the development group and the first period of routine group I. As a consequence the remodelling period also differs between the various groups, not in duration but with respect to its time relation to fixture installation.

corresponding figures for routine group I were 0.1 mm ($s=0.6$) and 0.1 mm ($s=0.5$) and for routine group II 0.1 mm ($s=0.6$) and 0.1 mm ($s=0.6$), respectively (Table 9). The figures given include cases with fractured fixtures.

Marginal soft tissues. The marginal periabutment tissues were generally found to be clinically healthy (Fig. 12), even when the periabutment mucosa was movable, provided

adequate oral hygiene was maintained. The gingival index for the entire material at the latest observation time – defined as the % of periabutment quadrants with gingivitis – was 6.7% ($s=19.5$). Cases with gingivitis generally responded well to improved oral hygiene procedures.

The thickness of the mucoperiosteum that covered the fixtures at the abutment operations

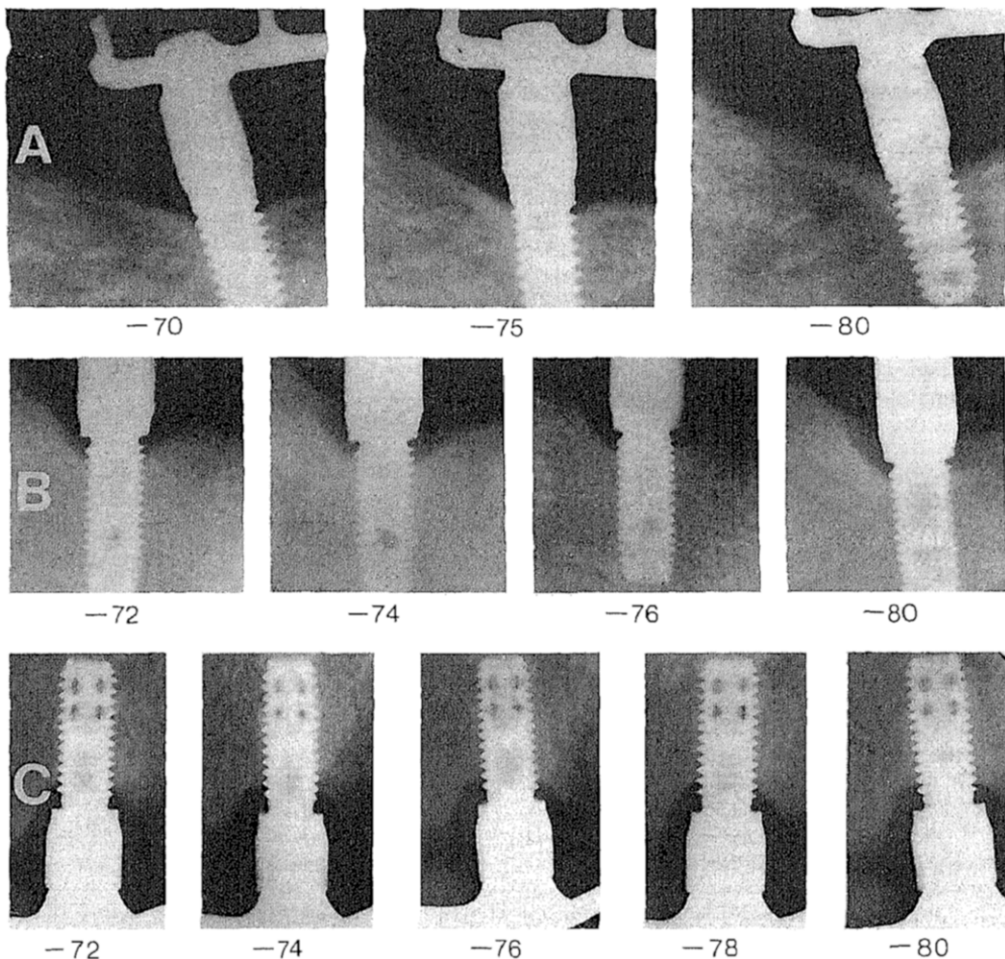


Fig. 11. Sequential roentgenograms of osseointegrated fixtures in edentulous jaws illustrating the behaviour of the marginal bone as an indicator of anchorage function. (A) Mandibular fixture at first registration and after 5 and 10 years, respectively. (B) Mandibular fixture followed for 8 years. (C) Maxillary fixture observed with 2-year intervals for 8 years.

initially determined the clinical depth of the periabutment pockets, as defined by probing. During the remodelling period there was a successive adaptation of the mucoperiosteum which became thinner and more firm.

In sample A (Table 3) the mean plaque and gingival indices were 13.7% ($s=21.5$) and 7.6% ($s=10.8$), respectively, 1 year after abutment connection. The mean clinical pocket depth was 2.6 mm ($s=0.9$) at the same time.

Adjacent structures

There have been no cases with persisting paresthesia or anaesthesia in adjacent nerves. When osseointegrated fixtures were in contact with the maxillary sinus or the nasal cavity, there were no adverse symptoms. Allergic reactions did not occur in the mucosa around the abutments.

Complications

A sample of 304 fixtures in 22 upper and 24 lower jaws from 16 males and 27 females selected at random and representatively reflecting the composition of the entire material was analyzed regarding the frequency of complications. This is called sample B below (Table 3).

Loss of anchorage function. Fixture anchorage was lost basically because of 3 different types of tissue reactions.

Osseointegration might not have been achieved due to *surgical trauma* or because of *perforation* through the covering mucoperiosteum during healing. Osseointegration could also be lost at an early stage as a result of *repeated overloading* with microfractures of the perifixtural bone. Finally, the fixtures could be lost because of *progressive marginal bone loss* subsequent to persisting gingivitis, successively depriving the fixture of its osseous support. Loss of fixtures in sample B during the healing and bridge loaded periods is reviewed in Table 10. The healing

period is defined as the time from fixture installation to abutment operation. Generally, mobile fixtures during this period were not identified until abutment connection. For the routine periods no major differences in the number of lost fixtures could be observed between healing and bridge loaded periods. The gradual refinement of the surgical method is reflected in the successively increasing number of fixtures which became osseointegrated (Table 10). The progressively better results may be related to improved fixture topography in relation to the residual jaw bone, to refined care of the flaps and the host bone at fixture installation, at suturing and during the healing period and to longer healing periods.

When fixtures were lost, their replacement had to be considered. Provided a sufficient number of osseointegrated fixtures remained, i.e. generally 4, having strategic positions with regard to the load distribution, additional installation of fixtures was not necessary. If the remaining fixtures were not sufficient in numbers or in adequate positions to provide bridge support, supplementary fixtures were installed as a rule during the second year. The treatment included the following steps. The mobile fixture was extracted and the thin encapsulating sheath of non-mineralized connective tissue was thoroughly removed from the walls of the fixture site. A muco-periosteal flap was mobilized to ensure a tight cover of the entrance to the site. After 9–12 months, new bone had formed with just a small dimple in the marginal bone as a remnant of the previous fixture site, and the same region could again be used for fixture installation¹⁴. Meanwhile the patient could usually wear the original bridge, sometimes after reduction of the load applied to the remaining fixtures, e.g. by shortening of the bridge extension. With proper care this kind of complication did not create any significant bone loss.

If a sufficient amount of bone for supplementary fixture installation was not present, grafting of bone as described by BRÄNEMARK *et al.*¹⁴ and by BREINE & BRÄNEMARK¹² was the treatment of choice.

Finally, extreme cases appeared – upper jaws only – where return to a removable denture was the only

Table 10. Number and % distribution of mobile fixtures during healing and bridge loaded periods in sample B

	Healing period		Bridge loaded period	
	Upper jaw	Lower jaw	Upper jaw	Lower jaw
Development group	13 25%	3 11%	4 8%	8 30%
Routine group I	11 20%	6 15%	9 16%	5 13%
Routine group II	2 4%	2 2%	– –	1 1%

realistic alternative. A definite return to a denture was necessary for 9 jaws (2.8%) of the entire material. In 4 of these upper jaws there was extreme resorption and the patients refused grafting of bone or were hesitant about such a procedure. 2 patients did not want to be reoperated after some of their fixtures had fractured because of inadequate bridge alignment to the abutments and subsequent undue stress concentration. 1 patient was not reoperated for psychiatric reasons, another patient was too old for reoperation to be considered and one patient died soon after having lost his upper bridge. In 4 of the 9 jaws described, the bridges had been stable for 2–6 years before failure.

Gingival complications. Three types of gingival complication occurred, namely early perforation, proliferative gingivitis and fistulae.

Early perforation of the covering mucoperiosteum during healing was often caused by decubital ulcers beneath the denture. Its frequency is indicated by an occurrence of 4.6% in sample B (Table 3). Active surgical measures were instituted with excision of bordering gingiva and full flap coverage of the perforation site.

When the marginal gingiva covered or closely approached the abutment-bridge junction this created unfavourable conditions for local tissue hygiene. As a result *proliferative gingivitis* occurred in 6.7% of the fixtures reported in sample B (Table 3). This required longer abutments, gingivectomy or flap procedures after adequate plaque control had been established. Apically repositioned flap operations and vestibular plasties were used to correct cases with inadequate width of attached gingiva and marginal muscle pull on the periabutment gingiva.

Fistulae penetrated the mucosa at about the level of the abutment-fixture connection in 1.5% of fixtures connected to abutments in sample B (Table 3). Fistulae especially occurred in those cases where the gingiva covered the abutment-bridge junction. At disconnection of the actual abutment in these cases, bacterial plaque were regularly found extending from the abutment-bridge junction along the central abutment screw. Adequate treatment consisted of surgical excision of the fistulous tract together with all granulation tissue circularly encapsulating the region of the abutment-fixture connection. The abutments were cleaned and sterilized and sealing agents were applied between the abutments and the bridge. Finally, the patients' hygiene efforts were particularly directed towards this area. Presently, the abutments are permanently sealed with an inert elastic material placed between the central screw and the outer cylindrical component.

Mechanical complications. In the total material of 1997 fixtures, 69 fixtures (3.5%: 54 maxillary and 15

mandibular) in 37 jaws (25 upper and 12 lower jaws) fractured at different levels. These fractures occurred 1–6 years after fixture installation, most of them after 5 years, only occasional fractures occurring after 7 years. In 26 of these jaws (70.3%), the fixtures had been connected to an intermediate type of bridge resembling that conventionally made on teeth in severe cases of periodontitis. The pontics and the lingual as well as the occlusal surfaces were made as heavy, rigid gold constructions with acrylic facings. Earlier and later in the project a less bulky bridge construction but with an optimal fit was used. This resulted in a subsequent marked decrease in the number of fractures.

Fixture fractures were often associated with accelerated marginal bone loss (Fig. 13). In a sample of 326 fixtures with various observation times called sample C (Table 3), 8% were found to have a marginal bone loss of about 3 mm a year. At re-examination of these fixtures, mechanical complications like screw, fixture and even bridge fractures, resulting in inadvertent stress concentrations, could always be demonstrated. In 5% of sample C there was a bone loss per year of 1 mm, probably caused by a period of stress concentration or long lasting gingivitis. In 87%, the yearly marginal bone loss was 0.1 mm.

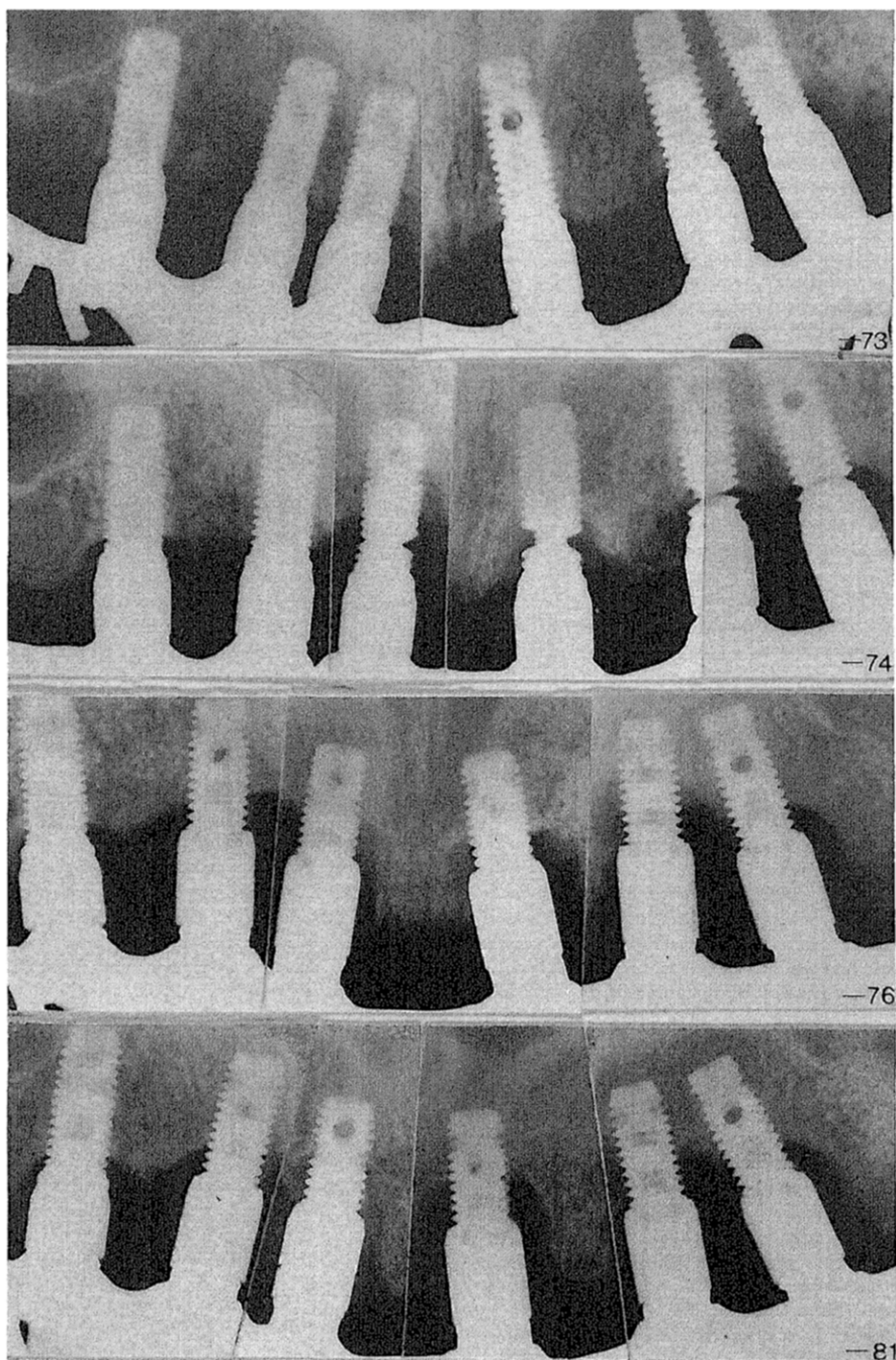
Small tooth movement, due to periodontal remodelling, can compensate for slight incongruencies between a gold bridge and prepared teeth after the bridge has been connected. The same possibilities, however, did not exist when the bulky gold bridges were tightly screwed to fixture abutments, which could not move at all. If absolute mutual congruency between bridge and abutments was not obtained, stress concentrations were induced in the fixtures. This was considered to be the most likely cause of the frequent fixture fractures that occurred in conjunction with these bridges. The risk appeared to be accentuated when the fixtures could be subjected to sudden sharp loads carried through the bridge in cases with porcelain or gold occlusal surfaces in the opposite jaw. Intense efforts have been taken to increase the precision in the fitting between the bridge and the abutments.

Other mechanical complications were fractures of bridges, of bridge locking screws or of abutment screws. These complications occurred in 4.9%, 1.5% and 3.0%, respectively in sample B (Table 3) and could be due to underdimensioning of mechanical components and/or inadequate stress distribution.

Discussion

Overall rehabilitation effects

When examining edentulous patients who



applied as candidates for treatment with fixed bridges on osseointegrated fixtures a great deal of hidden suffering was revealed, which was earlier inaccessible to therapeutic measures due to the lack of documented clinical alternatives to conventional removable dentures. Many edentulous patients thus preoperatively complained of gastrointestinal disturbances, reduced masticatory function, lack of self-confidence and as a consequence, often had to refrain from studies, professional work and social relationships^{9,10}.

The potentials of a rehabilitation method should be evaluated with regard not only to the compensation achieved for the local tissue defect but also to its influence on the total situation of the patient. In this respect the effects of the treatment were in many cases quite obvious¹⁰ as the patients normalized their social relations and enjoyed a considerably improved self-confidence. Furthermore, after oral rehabilitation, previous intentions for studies or occupation could be pursued.

Anchorage function

In routine group I (5–9 years) persisting fixture anchorage of 81% for upper and 91% for lower jaws was obtained (Table 4). The results from routine group II (1–4 years) indicate that even better results can be expected in the future.

The anchorage function is an overall representation of results obtained with regard to

fixture integration. It represents the quotient between the number of osseointegrated bridge-supporting fixtures and the total number of originally installed implants, no attention being paid to the cause of the fixture loss.

For the patient, bridge stability and function is of greater interest for his total rehabilitation than the fate of individual fixtures, although the latter control the long-term prognosis. Continuous bridge stability was achieved in 89–96% of the upper and 100% of the lower jaws for the routine groups (1–9 years, Table 5). In some of the cases, 1 or 2 fixtures were lost and replaced by new ones after bone had re-formed in the fixture sites.

The above-mentioned fixture and bridge "survival ratios" both reflect the somewhat better results obtained in lower jaws. Upper jaws generally had less total volume of bone available for anchorage due to vertical resorption which was often accentuated in cases where a residual anterior frontal dentition was present in the opposite jaw. Insufficient bone quantity could also be related to anteriorly expanded maxillary sinuses, to wide nasal cavities or to small bucco-palatal dimensions of the residual alveolar process, which often appeared to be as thin as cardboard, although the height of the residual bone could be considerable. The lack of sufficient width of bone for fixture installation in upper jaws was often not revealed by preoperative routine roentgen examinations.

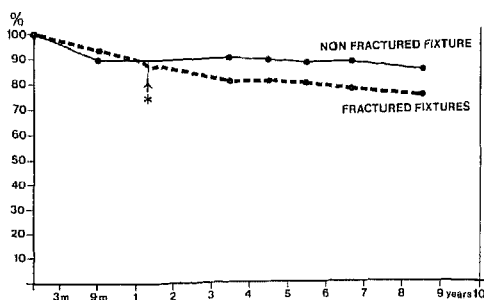


Fig. 13. Typical behaviour of anchoring bone close to fractured fixtures. In this case one fixture – the most distal fixture on the right side – remained intact and the 5 other fixtures fractured due to inadequate alignment of the bridge. When the abutment together with the fixture fragment could move relative to the still bone-anchored part of the fixture, the mucoperiosteum showed inflammatory reactions. There was concomitant and progressive loss of bone. When, however, repair had been performed with an adequately aligned bridge, the yearly loss of anchoring bone then returned to normal levels – as shown in the diagram – and the gingiva was healthy. * indicates time of fracture.

The inadequate bone anatomy of the upper jaws often required a time-consuming surgical exploration to locate sufficient amount of bone. If this procedure was not successful the use of preformed or immediate bone autografts as described by ADELL¹, BRÄNEMARK *et al.*¹⁴, BREINE & BRÄNEMARK¹¹ and LINDSTRÖM *et al.*³⁹ had to be considered. Moreover, maxillary bone density was generally less than that of the lower jaw. The problem was not only to achieve osseointegration of fixtures in the maxilla, but also to maintain it in the long run. Apparently the stress distribution was a more critical factor in the upper than in the lower jaw²⁵ because of discrepancies in bone biomechanics. This was shown to be especially true if the occluding surfaces were made of porcelain or gold. Acrylic occlusal surfaces appeared to act as some kind of shock absorber or were successively ground down by the patient, thereby compensating for possibly remaining minor occlusal irregularities. For the same reasons, the upper jaw was also more sensitive to any discrepancies in the adaptation of the bridge to the abutments. With this background, it was not surprising that in those cases where a definite (2.8% of the total number of jaws) return to removable dentures was necessary, *all* cases were upper jaws.

Our clinical experience indicates that treatment of the edentulous upper jaw often requires more technical skill than the lower jaw. The long-term clinical results achieved for even severely resorbed upper jaws indicate that the functional prognosis for the upper jaw is almost as good as for the lower jaw. These cases sometimes had remaining bone which did not allow anchorage for more than 4 fixtures and required careful surgical handling of the tissue, proper design and alignment of the bridge and careful successive adjustment of the occlusion. The special requirements on technique and resources in the treatment of upper jaws should, however, be considered when indications for treatment are evaluated. Patients who were edentulous in both the upper and the lower jaw often complained of predominant problems

from the lower jaw. For the above reasons treatment with bone anchored bridges in completely edentulous cases always started in the lower jaw. The patients often expressed their satisfaction with wearing a denture in the upper and a fixed bridge in the lower jaw and no further treatment was required.

The results of the development group with regard to persisting fixture anchorage in both jaws (Table 4) and continuous bridge stability in upper jaws (Table 5) reflect the more heterogeneous therapeutic approaches used during this project period. Although the same basic principles of treatment were applied, too short a healing time for obtaining osseointegration in residual bone with varying biomechanical characteristics, was sometimes allowed in this group.

Osseointegration

What evidence do we have for the existence of permanent integration of titanium fixtures in jaw bone?

1. In experimental studies in dogs² it was not possible by use of orthodontic appliances to move fixtures by variation of either the direction or the magnitude of the load applied.
2. In the clinical material, fixtures which roentgenographically appeared osseointegrated, could not be extracted or even rotated. This was also true for cases with just a few fixture threadings remaining in bone, when a considerable loss of marginal bone height had occurred. On the other hand, fixtures which were surrounded by a perifixtural radiolucency were easy to remove.
3. Clinically stable fixtures in the roentgenograms were surrounded by normal trabecular bone in intimate contact with the fixture surface. Mobile fixtures, on the other hand, lacked this contact as they were surrounded by a thin perifixtural radiolucency.
4. In several cases a perifixtural radiopacity developed around integrated fixtures, indicating a successive load-related bone

remodelling. This gradual corticalization also occurred within primarily cancellous bone and even within autologous bone grafts¹¹.

5. Histologic sections of fixture sites^{14,6} for clinically stable fixtures have shown remodelled bone with osteocyte-filled lacunae in close approximation to the fixture surfaces. No non-mineralized connective tissue has been shown interposed between the fixtures and the bone sites. Such a sheath of tissue was regularly present – clinically and histologically – if the fixtures had shown any evidence of clinical mobility. This is in full accordance with earlier experimental findings¹³. The possibility even exists of a direct bonding between the fixture surface and the enveloping bone⁶.
6. 10 osseointegrated and bridge-supporting fixtures were removed together with the surrounding tissues for scanning and transmission electron microscopic analyses⁶. 9 fixtures were removed from maxillary sites and 1 from a mandibular site. In 1 of the patients 6 upper jaw fixtures were removed for psychiatric reasons; the remaining fixtures were removed because of fractures. The observation times were 30 to 90 months. Until removed for the above reasons, these fixtures were included in the reviewed material.

Cell processes from both bone and marrow cells were strongly adherent to the titanium surfaces and could be seen glued to the titanium oxide surface of the fixtures by an amorphous ground substance layer of proteoglycans of a few hundred Å thickness. There was an intimate topographic relationship between the fixtures and the bone without any interposed non-mineralized connective tissue. No signs of corrosion were noticed as only calcium was found on the fixture surfaces, with no titanium on the investing bone at ion probe analysis⁶.

7. At one osseointegrated fixture of the above material, ALBREKTSSON *et al.*⁶ were success-

ful in cutting (and producing transmission electron microscope sections) through the implant and the investing bone without disrupting the mutual connection. An intact bone-implant interface without intervening connective tissue was revealed at analysis.

The long term stability and capacity of the fixtures to carry occlusal load and stress from various directions through the years even under unfavourable mechanical circumstances appear to be a result of the fact that the fixtures were osseointegrated. So far, no corresponding *long-term consecutive* clinical results have been published for endosseous implants in completely edentulous jaws.

Marginal bone height

Marginal bone was lost both during the healing period when the fixtures were covered by mucoperiosteum, and later, after abutment connection. During the healing period, more bone was lost in upper than in lower jaws, while the reverse was true for the remodelling period, i.e. the first year after abutment connection (Table 8). This might be related to differences in remodelling capacity and rates between maxillary and mandibular bone. Because of the rich vascular supply and the cancellous character of the maxillary bone much of the necessary remodelling after fixture installation could occur during the healing period, while the slower reacting compact mandibular bone demanded an extended period of time for the same purpose. The decreasing values of marginal bone loss during the healing period (Table 8) for the 3 project periods is probably explained by successive refinement of the surgical technique. The higher values for bone loss in the remodelling period (Table 8) might be explained by the higher torque forces applied at installation of fixtures²⁵ in the routine groups.

The total marginal bone loss from the beginning of the healing period to the end of the remodelling period was, however, almost equal in all the 3 groups and was about 1.2 mm. During the follow-up periods, i.e. the observ-

ation time after the first year with the fixtures bridge-loaded, the mean annual bone loss was 0.1 mm in the routine groups (Table 9). Thus, it appears that – with regard to marginal bone height – a reliable long-term prognosis can be estimated after 1 year.

The marginal bone loss could be attributed to several factors:

1. Effects of surgical trauma such as detachment of the marginal periosteum, removal of marginal bone and bone damage at drilling.
2. Inadvertent stress distribution to the marginal bone by forced tightening of the fixtures at installation²⁵ or by later inadequate loading. This could be related to a number of factors.
 - a. Trauma from occlusion and/or from unfavourable relations between the jaws, even with a properly designed bridge.
 - b. Defective bridge design concerning adaptation to abutments, occlusal adjustment, extension, etc.²⁴.
3. Physiological resorption of the edentulous jaw.
4. Gingivitis which, if untreated and allowed to progress down to the periosteum, may in the long run cause bone resorption.

The annual decrease in marginal bone height for the follow-up periods is comparable with or even less than the loss of attachment level or marginal bone height at teeth reported for patients after treatment for severe periodontitis with the same postoperative control intervals, 6–12 months^{37,62,53} and control groups in NYMAN *et al.*⁵⁰, ROSLING *et al.*⁵⁶, ROSLING *et al.*⁵⁷, AXELSSON & LINDHE⁷. In some of the investigations referred to^{50,56} the control patients lost about 1 mm of periodontal support per year. Provided that the periabutment and perifixtural tissues react in the same way as the periodontium to the presence of microbial plaque, even better results than hitherto obtained might be expected with more frequent hygiene controls for patients with bone anchored bridges (test groups in LINDHE &

NYMAN³⁸, NYMAN *et al.*⁵⁰, ROSLING *et al.*⁵⁶, ROSLING *et al.*⁵⁷, AXELSSON & LINDHE⁷). This would require a different organization of our control system, e.g. referring patients with bone anchored bridges at regular intervals to local hygienists or to regional clinical centres. It should also be observed that the present figures for marginal bone height decrease included those cases where fixtures had fractured. Such fractures often caused a severe loss of bone. After adequate treatment, however, even these fixtures remained integrated with favourable prognosis.

The amount of marginal bone loss was also in good agreement with the yearly loss of bone height reported for edentulous jaws in patients with removable dentures^{67,16,63,20}. The loss of bone in such cases may be due to lack of mechanical stimuli, transferred to the jaw bone. In this context it is of interest to note that as time progresses the marginal bone level can remain at a more coronal level close to the fixtures than further away. This could be interpreted as though the fixtures exerted a stimulating influence on the remodelling perifixtural bone. The same view is supported by model studies²⁵ and by histologic findings from experimental series¹³ showing a horizontal architecture of perifixtural bone trabeculae emanating from the tip of the fixture threadings. It is also supported by roentgenographic examinations of fixtures showing increasing perifixtural radiopacity through the years.

When interpreting postoperative variations in marginal bone heights at fixtures, it is important to keep in mind the varying pre-operative topography of the marginal bone. In a great number of cases the residual alveolar crest was extremely thin in the bucco-lingual direction, a condition which had no apparent relation to the clinical width or height of the gingival crest and which was not always fully revealed by the roentgenographic examination. In order to provide complete osseous coverage of the fixture it was in such cases necessary to resect some marginal alveolar bone locally until

a sufficient bucco-lingual width was reached with regard to the fixture diameter (Fig. 11). Moreover, it was necessary to provide space for the fixture holder – also representing abutment dimensions – at installation of the fixtures. The marginal defects which were thus created surgically may, especially after remodelling, erroneously be diagnosed as vertical bone destruction due to their geometric similarity with such defects at teeth with periodontitis.

Marginal soft tissues

The marginal periabutment tissues should constitute a functional barrier between the oral environment and the host bone by sealing off the osseous fixture site from noxious agents, and thermal and mechanical trauma. The ultimate function of the soft tissue barrier is reflected in the long term changes of the marginal bone height.

It might be tempting to apply periodontal investigative methods to study the condition of the tissues surrounding fixtures and abutments. Until the possible relevance of these methods has been proved for a situation which is very different from that of the tooth, these methods can, however, not be reliably used for revealing the status of the tissues surrounding osseointegrated implants.

If granulation tissue occurred at the junction of abutment and fixture it was a common occurrence that the inflammatory exudate did not pass between abutment and mucoperiosteum into the gingival pocket, but was instead drained via a fistula penetrating the buccal mucosa. This indicates that there may be a bond between the gingival pocket lining and the abutment surface. A connection of this kind does not appear inconceivable in the healthy state since relationships closely resembling normal epithelium-enamel junctions have been found between gingiva and various restorative materials⁴⁷. The same also holds true for implant abutments according to JAMES & KELLN³⁵, JAMES & SCHULTZ³⁶ and SCHLEGEL *et al.*⁵⁸. Finally, it should be noted that a

junctional epithelium, which is necessary for a normal epithelial attachment to tooth surfaces, can be regenerated from oral epithelium⁶⁰.

The concept of a direct attachment between gingiva and abutment was strongly supported by ALBREKTSSON *et al.*⁶ where electron-microscope analysis of abutments removed from patients showed epithelial cells of normal size and shape, glued to the titanium oxide surface by a thin layer of proteoglycans. No inflammatory cells were found in this region. These findings are in full accordance with the histologic observations of BÄRNEMARK *et al.*¹⁴.

It is important to maintain adequate oral hygiene in cases with bridges on osseointegrated fixtures. As a majority of the patients in our material resided far from the clinic, the number of oral hygiene check-ups after the first year was limited to 1 or 2 visits a year. The patients were, however, highly motivated for plaque control as they had earlier experiences of edentulousness, often caused by periodontitis. At a recent control of our entire material, plaque at the abutment-gingival junction was found to cause gingivitis in 6.7% of the periabutment quadrants. There appeared to be less plaque formation, however, on abutments than on dental surfaces in corresponding positions. This may be explained by differences in surface characteristics between teeth and titanium²².

At the 101 fixtures and abutments examined one year after bridge connection, sample A, (Table 3) the mean values for gingivitis and plaque % indices were 7.6 and 13.7, respectively. This is regarded as a satisfactory result considering the 6-month intervals between the oral hygiene re-instructions in this group.

Plaque may not be the only cause of gingivitis at abutments and fixtures. Even if the movable mucosa around the abutments was generally clinically healthy, cases were seen where the mucosa had apparently been traumatized by the most marginal fixture threadings after some bone resorption had occurred. The passage of abutments should therefore be preferably located in attached gingiva. If sufficient width of

such a tissue was not available, gingivo-vestibular plasties were performed with encouraging results. The surgical procedures were facilitated by the possibility of retaining a surgical pack under the fixed bridge.

The mean pocket depth for sample A (Table 3) was 2.6 mm, a value which at teeth would have indicated a healthy situation. This sample of fixtures and abutments is continuously being followed. After a further 2-year period, biopsies of the marginal soft tissues at these abutments will be taken in order to elucidate the true nature of the gingivo-abutment junction.

Material

A majority of the patients had a long period of edentulousness compensated with dentures. Generally their alveolar processes were resorbed to an advanced degree. They had long tried to adapt themselves to function with removable dentures but with poor results. Besides, no realistic therapeutic alternatives had been available to them, so far. In many cases a complex psycho-social insufficiency situation had developed which was revealed during the treatment.

It should be emphasized that this review is based on a consecutive material of completely edentulous jaws representing a great number of extremes with regard both to age variations and differences in jaw bone anatomy and quality.

For 65 jaws the observation time exceeded 10 years (Development group, Table 2) and for a further 130 jaws the observation time was more than 5 years (Routine group I, Table 2). For bridges on teeth, a maximum function time of 10 years is regarded as a very good result and a 15-year bridge function is regarded excellent^{15,27}. The 5-year limit is a common reference time for comparison of results of different treatment methods in the medical and odontological literature (*cf.* IZIKOWITZ²⁰). It was also specifically used and recommended by the 1978 Harvard Conference²⁹, assessing and evaluating various oral implantation procedures. It thus appears fair to evaluate the results with special

attention to those cases which had an observation time exceeding 5 years. It is reasonable to expect that the results of the development group should be less favourable than those of the routine periods. Therefore, the results of routine group I with 895 fixtures in 130 jaws (Tables 1 and 2), are regarded as those presently most correctly reflecting the potentials of the osseointegration method (Fig. 14).

Method

The principle prerequisites for osseointegration – as described by BRÄNEMARK *et al.*¹⁴ and by ALBREKTSSON *et al.*⁶ – are the implant material, its design and finish, the condition of the investing bone, a delicate surgical technique and

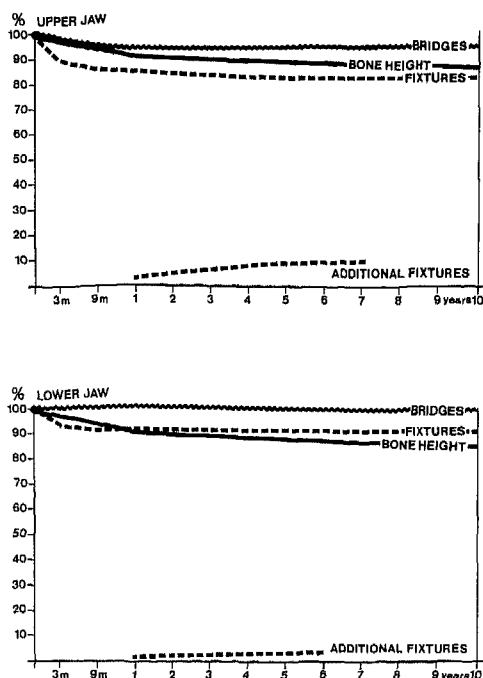


Fig. 14. Diagrammatic representation of clinical results obtained in a consecutive series of edentulous cases, treated with osseointegrated bridges and followed for 10 years with yearly controls. The % of integrated fixtures, stable bridges and behaviour of anchoring bone – as evaluated by roentgenologic assessment of marginal bone height – is shown, as well as the number of additional fixtures installed.

a sufficiently long healing period before exposing the implant to the load of a bridge.

Choice of implant material, design and finish.

Titanium was chosen as implant material as it had favourable mechanical properties in relation to bone¹⁴. In theory, a potential capacity was also regarded to exist for the formation of a chemical bond between the firmly adherent titanium oxide layer and the tissues. Titanium may in fact be regarded as a ceramic rather than a metal⁶ because of this stable oxide layer. Furthermore, titanium has been reported to have a low toxicity and to be most resistant to corrosive forces in the body environment (for review see ALBREKTSSON *et al.*⁶).

The screw design provides superior mechanical stability and great initial resistance to shear forces in comparison with other surface-enlarging designs, as e.g. in those incorporating porosity of the implant surface. A micro-grooved surface has empirically been found to promote osseointegration¹⁴.

Surgical treatment. An important feature of the osseointegration method is the emphasis put on efforts to minimize any damage to the host tissues, by e.g. contaminants, thermal or surgical trauma. The surgical method is not complicated but requires a great deal of precision and care – the limits for acceptable tissue handling being much narrower than in general oral surgery. Any divergence from the principle of least possible trauma at installation of the fixtures increases the risk for loss of osseointegration and subsequent occurrence of a thin perifixtural zone of connective scar tissue. This especially applies to the effects of thermal trauma as studied by LUNDSKOG⁴¹.

Bone cutting in relation to bone trauma has recently been thoroughly reviewed by LINDSTRÖM *et al.*³⁹, the recommendations given below being emphasized. Any drilling in bone tissue should be performed under constant and profuse irrigation^{34,43,28,31}. All cutting instruments should be well sharpened^{51,52,48,18,43} and should be designed to allow for the cooling fluid to pass to the very bottom of the site under

preparation, thus also removing cut material. The drill pressure and the drill speed should both be kept low^{64,31,33}.

If preparation of bone tissue is carefully handled in the manner described, a high percentage of osteogenic cells can survive and remain active, even after transplantation (for review see ALBREKTSSON *et al.*⁵, ALBREKTSSON⁴, BREINE & BRÅNEMARK¹¹).

The potentially osteogenic periosteal cells should be preserved by minimal surgical trauma to the mucoperiosteal flap (BRÅNEMARK & BREINE¹², MELCHER & ACCURSI⁴⁶, ADELL¹) and the bone surface should not be deprived of its periosteal vessels if avoidable¹⁴.

Prosthetic treatment. "Atraumatic" surgery must be followed by "atraumatic" prosthodontics, i.e. a prosthodontic treatment where full attention during all phases is paid to proper stress distribution. Otherwise, an initially established osseointegration may later be lost due to undue local stress concentrations¹⁴. This especially applies to 4 situations – relining of the denture after fixture installation in order to avoid decubital ulcers, designing free extensions of the bridge, adaptation and fitting of the bridge to the abutments, and finally, adjustment of the occlusion to the opposing jaw. If the latter 3 factors are not given due attention, fractures of the mechanical components: bridge, screws, abutments or fixtures, or microfractures of the bone anchoring the fixtures will sooner or later occur.

In severely resorbed cases, there were often inverted relations in the sagittal plane between the residual upper and lower alveolar processes in the frontal region. The bridges had to compensate for both the loss of teeth and for the severe resorption of the alveolar bone in the vertical and horizontal directions. This called for a special design of upper jaw bridges¹⁴ with increased cantilever effects onto the fixtures which, as stated above, were often situated in bone of reduced mechanical strength. The design of upper jaw bridges not infrequently entailed some initial difficulties in giving the

patients pleasing esthetics and adequate phonation. The bone anchored bridges so far used did not include a prosthetic substitute to compensate for resorption of the alveolar process in the horizontal plane.

Summary and conclusion

1. Osseointegration implies a direct and intimate incorporation in vital bone of threaded titanium fixtures of defined finish and geometry.
2. Osseointegration can be achieved if fixtures are inserted with a delicate surgical technique and are allowed to heal without load for periods of not less than 3–4 months in lower and 5–6 months in upper jaws.
3. In upper jaws 81% of the originally installed fixtures remained stable and supported bridges after 5–9 years. Continuous bridge stability was achieved in 89% of these jaws.
4. In lower jaws 91% of the original fixtures were stable and bridge supporting after 5–9 years. Continuous bridge stability was attained in 100% of these jaws.
5. The mean bone loss was 1.5 mm during the healing period and the first year after abutment connection. Thereafter only 0.1 mm of marginal bone was lost annually in the group observed for 5–9 years.
6. In the routine case the fixtures and their abutments are surrounded by hard and soft tissues which have remained healthy for follow-up periods of up to 15 years, thus far.
7. The small number of fixture losses and the low values of the mean annual marginal bone loss in the follow-up periods indicate that a reliable prognosis can be made in the individual case after the first year has passed.

The results also point to the great confidence with which the patients can rely upon the anchorage of their bridges.

8. The fixture-supported bridges have been shown esthetically, phonetically and func-

tionally to restore the masticatory system of edentulous patients for, so far, 15 years.

9. The method, in all respects, fulfills and even exceeds the demands by the 1978 Harvard Conference⁵⁹ on a successful dental implantation procedure.
10. Treatment with bridges on osseointegrated fixtures implies not only an oral rehabilitation but also a considerable positive impact on the psycho-social situation of the patient, earlier suffering from edentulousness, inadequately compensated by dentures.

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