INTRA-OSSEOUS ANCHORAGE OF DENTAL PROSTHESES

I. Experimental Studies


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Abstract. An investigation of factors controlling healing and long term stability of intra-osseous titanium implants to restore masticatory function in dogs revealed that an integrity of the good anchorage of the implant requires: (1) Non-traumatic surgical preparation of soft and hard tissues and a mechanically and chemically clean implant. (2) Primary closure of the mucoperiosteal flap, to isolate the implant site from the oral cavity until a biological barrier has been reestablished. (3) Oral hygiene to prevent gingival inflammation. Provided these precautions are taken, it is possible to subject dental prostheses, connected to the implants, to unlimited masticatory load. With these precautions such implants were found to tolerate ordinary use in dogs for periods of more than 5 years without signs of tissue injury or other indications of rejection phenomena.

Macroscopic clinical investigation, stereomicroscopy, roentgenography and light microscopy of the implant site in situ and after removal from the body showed that the soft and hard tissues had accepted the implant and incorporated it without producing signs of tissue injury. In fact the bone appeared to grow into all the minute pits and impressions in the surface of the titanium implant, without any shielding layer of buffer tissue at all.

These findings indicate that dental prostheses can be successfully anchored intra-osseously in the dog suggesting that its possible clinical use in oral rehabilitation should be given unprejudiced consideration.

Attempts have long been made to devise a method for securing permanent anchorage of artificial dentures, total or partial, especially since retention of such dentures by conventional methods is difficult or sometimes even unacceptable. This is particularly apparent in cases where psychiatric and occupational factors make it difficult to use conventional removable dentures.

In some cases there is thus an obvious need for a permanently anchored artificial denture; this is also evident from the increasing number of models and methods of dental implants that have been tried in the last 10–15 years.

Though numerous types of implants have been tried, two main groups may be distinguished: a subperiosteal type and an intra-osseous type (Fig. 1). The former type consists of a more or less fine-meshed framework, which is inserted between the jawbone and its periosteum either as a single piece or in separate parts. From this framework or scaffolding abutments project into the oral cavity, where they serve as anchors for the artificial appliance.

At installation the bone in the area in question is exposed by raising a mucoperiosteal flap, after which an impression is made of the bone. The implant is shaped accordingly and, after a varying interval, it is inserted.

In the other main group, the intra-osseous group, various types of screws, posts or pins are anchored in the bone and projecting through the mucoperiosteum by an abutment for the appliance.

There are also methods which combine these two procedures, and one method consisting of implantation of magnets in the bone for retaining a magnetic appliance. The implants hitherto used consist mainly of stainless steel, chromium–cobalt–molybdenum alloys, tantalum or titanium.

Most investigations on humans comprise only a few cases, mostly running for a more or less...
Intraosseous implant.

Fig. 1. Schematic representation of the principles for subperiosteal and intraosseous dental implants. (a and b) Alveolar process of upper and lower jaw bone, respectively, with soft tissues. (c) Subperiosteal implant. (d) Intraosseous implant.

Methods of evaluation and results

Most methods used in the evaluation of the results of experimental investigations are the same as those used in clinical studies, e.g. roentgen-examination, examination of gingiva, mobility test and histologic examination. In research on implantation in animals it is more or less the rule to deposit the implant subperiosteally. Thus, Capozzi (1954) reported subperiosteal mandibular implants in 12 dogs. The tissues i.e., gingiva, periosteum and bone, in direct contact with metal (chromium-cobalt-molybdenum alloy) showed histologic changes resembling those seen in common unspecific, mild chronic inflammation viz. chronic hypertrophic gingivitis and chronic osteitis. The duration of the experimental period was not given. Nichols (1954) inserted subperiosteal implants of the Gershkoff & Goldberg (1957) type in one half of the lower jaw of six dogs. However, the implants were not loaded. Four of the implants were screwed to the underlying bone, but the mucosa over the screws was irritated; therefore no screws were used in the remaining two cases. In two cases a second operation was necessary to cover the implants with a flap. The implants were left in situ for 2–5 months, but none were successful for more than 4½ months. The author concluded nevertheless that the material used, a chromium-cobalt-molybdenum alloy, Vitallium, did not give rise to inflammation. The mucosa could be blown away from the implant abutments by an air stream. Epithelial cells migrated down between the implant and the soft tissues and the amount of epithelial downgrowth was proportional to the time the implant had been used. There was severe inflammatory infiltration around the abutments. The intensity of the inflammation decreased with the distance from the abutments. In the deeper part, the implant did not remain in contact with the bone. There was osteoclasia and a layer of connective tissue between the bone and the metal. Herschfus (1955 a) studied histologic sections of a six month old Vitallium subperiosteal implant in a dog. Sections obtained from the area of the metallic insert revealed a quiescent squamous epithelium with pockets near the post. The rete pegs were prominent, but no significant histopathological changes were seen in the squamous epithelium. Immediately beneath the latter a few lymphocytes and plasma cells betrayed the presence of a slight inflammatory process but no other changes were seen. In a later publication Herschfus (1955 b) reported Vitallium implants in the upper jaw in dog which had been worn from 14–16 months. Immediately adjacent to the abutments the stratified squamous epithelium of the gingival margin dipped downward. The epithelium itself was slightly keratotic, quiescent and showed no significant histopathological changes. In an additional section, the termination of the squamous epithelium was followed by a thin zone of granulation tissue containing a scanty infiltration of lymphocytes and plasma cells. As indicated

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1 For review of literature on clinical investigations see part II of this series to be published in next issue of this journal.
above, no evidence of a distinct pocket was found between the gingival tissue and the posts of the implants. The corium adjacent to the implants consisted of almost avascular dense collagenous connective matrix and a few chronic inflammatory cells. Some sections exhibited a mildly hyperemic granulomatous zone immediately adjacent to the metal; the zones were slightly infiltrated by lymphocytes and plasma cells. In the deeper layers, the fibroblastic tissue was intimately fused with the periostium and both elements apparently completely filled interstices of the meshwork. The actual bone was composed of the usual osseous trabeculae separated by somewhat fibrotic marrow. The fibrotic changes were particularly prominent immediately adjacent to the root portion of the implant. No evidence of a foreign body or other significant inflammatory reaction was observed.

Reichenbach & Naucke (1955) extracted teeth from the right lower jaw of dogs and inserted subperiosteal implants of a chromium-cobalt-molybdenum alloy, called Wisol. They said that the implants were "naturally not loaded" during the experimental period of two months. The histological analysis disclosed a mucous membrane enclosing the abutments, like tight rubber cuffs, but with an intermediate macroscopic space. The pockets of the abutments were epithelialized down to half of their depth. No granulation tissue or other signs of inflammation were found. The metal was never found to lie in direct contact with the bone, but was always separated from it by connective tissue. No active osteoclasts were seen.

Weinmann (1956) discussed biological factors liable to jeopardize the success of the implanted anchors for dentures. According to this author, at least three questions must be answered before it can be explained why implants might be tolerated by the jaws: (1) What mechanism prevents the invasion of bacteria around the abutment posts? (2) Why is the bone not resorbed under the pressure of the implant? (3) How does the bone react to the insertion of the implants? Herschfus (1957) compared the histopathologic findings of two maxillary Vitalium subperiosteal implants which had been in situ in dogs for five years but unloaded. One implant was successful, the other a "failure case". The features of the sections from the former case were about the same as those the author had seen in previous studies. In the latter case there was a mass of necrotic debris swarming with micro-organisms. The tissue at the base of the implant was covered by epithelium and infiltrated by mononuclear cells. The cortical bone adjacent to the implant was covered by a thin periostium, above which there was fragmented fibrous connective tissue with areas of degeneration and marked inflammation. Sections of cancellous bone showed no significant histopathologic changes. The cancellous bone contained normal marrow elements with trabeculae. Despite soft tissue changes with necrotic tissue and chronic inflammation of the connective tissue there was no evidence of inflammation or degeneration of the bone.

Mack (1960) studied two Rhesus monkeys, one of which received a mandibular subperiosteal implant for one year; the other, both a mandibular implant for 293 and maxillary implant for 251 days. The implants were partial and made of a chromium-cobalt alloy. A method for sectioning and staining specimens with the metal implants en bloc was used in the evaluation of the tissue reactions. The framework was found to be mechanically retained in position by the fibrous tissue which had developed around it, and in most of the sections there was a lining of epithelium between metal and fibrous tissue.

According to Mack (1960) the tissue injury phenomena following insertion of implants can be interpreted in the following way. There is a moderate inflammatory reaction of the tissues when the implant is inserted. This is followed by the formation of fibrous tissue around the framework and by an epithelial downgrowth, which is a healing process. The epithelial reaction will eventually enclose the entire framework in a bed of epithelium surrounded by fibrous tissue, so that the metal is in effect external to the body.

Schwindling (1960) used annular implants made of steel or gold and inserted them through the submucous tissues or buccal muscles in dogs. No prostheses were applied, but the author felt that chewing placed a severe stress on the implants. After 6 to 13 weeks histologic examination revealed a chronically inflamed granulation tissue subepithelially. Sometimes the channels from the implants were partially epithelialized.

Hoppe (1961) approached the problem of tissue reactions to subperiosteal implants from another angle. He used 2 experimental series. The first consisted of two dogs, in each of which three separate subperiosteal implants were inserted in the palate. The base part of the implant was made of acrylic plastic and the abutment of metal, "Remanit-G". By control 6 weeks later the tissue had healed and the implants showed no mobility. Neither was there any pocket more than 1 mm deep. To test the efficiency of the tissue barrier a test solution of India ink was carefully sprayed into the pockets. Later histologic examination revealed no ink-particles at the bottom of the pockets.

In the second series, 4 dogs were used and 8 implants of the same type as described above were inserted. After a healing period of 4 weeks to 6 months a test-solution with Fe111-ions was applied for 2 to 3 min according to the method described above. Histologic control showed that the epithelial cuff was so dense that the Fe111-ions had not passed into the underlying connective tissue.

Toto, Coukas & Sanders (1962) implanted platinum-cobalt alloy magnets in the body of the mandible of 10 dogs. The magnets were studied for any migration in the bone, and were found to be well accepted by the osseous and fibrous tissues. When two attracting magnets were implanted with only 1.5 mm of intervening bone, the latter atrophied owing to compression by the approximating magnets.

In a later study Toto, Coukas & Abati (1963) used 10 dogs for installation of implants of magnetized platinum-cobalt alloy in the body of the mandible on one side. A similar non-magnetic alloy was implanted in the opposite side of the mandibular body to serve as control. The animals were sacrificed at intervals of 24 hours to 6 months. The implants became completely enclosed in a dense fibrous capsule. The outer surface of this capsule was found to be continuously connected with the reconstructed periostium lining the bony vault. A platinum-
cobalt alloy, magnetized or non-magnetized, was, according to the author's interpretation of these results, apparently innocuous when implanted in bone. Reichenbach & Köllner (1963) found a resting and inactive bone under unloaded subperiosteal implants in dogs.

Herschfus (1964) examined the microscopic appearance of tissues round mandibular intraperoisteal implants of Vitallium in dogs. The stratified squamous epithelium of the gingival margin adjacent to abutments dipped slightly downward. The epithelium itself was slightly keratotic, quiescent and showed no significant changes. In an occasional section, the termination of the squamous epithelium was followed by a thin zone of granulation tissue containing a scanty infiltration of lymphocytes and plasma cells. Epithelial downgrowth along the implant, or a typical epithelial hyperplasia, was not observed. The lower third of the submucosa revealed spaces of varying size, from which the Vitallium struts had been removed. In some areas there were large calcified masses at the edges of these spaces in connection with minute areas of new fibroblastic proliferation, containing numerous capillaries.

The deepest portions of the submucosa contained a compact mixture of proliferating fibroblasts and periosteal fibres. The underlying osseous and marrow tissues were of normal appearance.

Hodosh (1966) reproduced extracted teeth in synthetic material and inserted them into the empty sockets. The implants were fixed to the remaining teeth by intra-coronal fixation. The investigation was performed on monkeys, especially baboons, in which the masticatory load is considerable. The inserts were left in position for 6 months to 2 years. Clinically, the gingiva was normal except for the first few weeks. The histologic examination showed normal tissues with bone-fibre-like periodontal fibres parallel to the long axis of the implants.

Shklar, Hodosh & Povar (1966) reported the fate of 150 implants inserted by the method of Hodosh (1966) in baboons. Vitallium pins through the bone and the implant at the apical region were used for fixation. During an experimental period of 3 to 5 years the implants were exposed to heavy masticatory load but no oral hygiene measures were taken. A pocket depth of 2–3 mm was generally found at the end of this period. Gingivitis had occasionally been observed and in these cases the implants offered considerable resistance to extraction. Histological examination of the tissues adjacent to the implant showed periodontal-like fibres parallel to the implants and an osteoid zone in the bone. The epithelial attachment therefore resembled that of a normal tooth. It appears to the authors of the present paper, however, that unfortunately the design of the experiment by Hodosh et al. did not correspond to the situation encountered in patients requiring an artificial denture.

In a later investigation Hodosh, Povar & Shklar (1967) studied 6 plastic implant teeth, exact replicas of extracted natural teeth, provided with wide channels cut through the roots in a horizontal direction. Five maxillary and one mandibular incisor were extracted on baboons and plastic tooth implants, exact replicas of extracted incisors, were inserted into the empty sockets. The replicas were inserted within minutes. They were splinted to adjacent natural teeth by stainless steel wires and self-curing acrylic.

The plastic tooth implants were clinically firm after periods from 6 to 12 months. Microscopic observations revealed osseous bridges that had developed through the horizontal channels cut through the roots of the plastic implants. Where the periodontal tissues were well adapted and the gingival inflammation was minimal the osseous root bridges were well developed and free of inflammatory infiltration. There was a connective tissue similar to a periodontal membrane adjacent to the plastic surface of the root. The bone was well adapted.

In one instance the channel was in the coronal part of the root close to the gingival sulcus. Here an osseous bridge developed but with inflammatory infiltration related to a deepened gingival sulcus. The authors conclude that the development of horizontal osseous bridges will serve to anchor the implant more firmly within the socket.

Hodosh, Povar & Shklar (1968) have also been able to demonstrate connective tissue fiber attachment between almost normal alveolar bone and six implanted plastic teeth on baboons. The fibers entered deeply into the plastic material and often formed a network in the apical root area.

In investigations of tissue reactions to implants two main problems have received much space in the literature. One bears mainly on the reaction of epithelium and other soft tissues and their connection and relation to the abutments. Nichols (1954) and Cherchève (1962, 1966) hold quite different opinions; the former claiming that every break of the continuity of the epithelium is against Nature's laws, a postulation challenged by the latter. The other problem is that of bone and marrow reaction to the implantation procedure, to the implant material and to the load on the implant.

GENERAL CONSIDERATIONS AND BACKGROUND OF THE INVESTIGATION

It is clear from this review of the literature that so far no objective complete experimental analysis has been made of the biological prerequisites for permanent anchorage of a dental prosthesis in the jaw bone. Neither have observations made in clinical studies produced data allowing an analysis.

If implantation is to be applied clinically, the method should first be studied experimentally on animals and not, as now appears to be the rule, by trial and error in homo. Animal experiments provide a possibility of testing various modifications of implants and materials, of trying out various technical procedures for the insertion of such implants as well as histological and other investigations of the reaction of the tissue round the implant. Such experiments are also necessary to assess the stability of the anchorage of an implant and the variation of stability with the shape of the prosthesis and the loading of the implant.
Knowledge gained in previous studies on the function of nutritive capillaries in bone marrow with the use of the vital microscopic chamber technique was utilized as a starting point in our approach to the present problem (Bränemark, Breine, Johanson, Roylance, Röckert & Yoffey, 1964). In those studies appliances made of titanium were inserted through covering tissues and implanted in the tissue to be studied by specially devised microsurgical methods involving as little trauma as possible. This analytical "non-traumatic" method yielded, among other things, valuable information on the reaction of the hard and soft tissues to the unavoidable installation trauma and to the implanted metal. With this technique it was possible to secure a firm anchorage of the titanium appliance in the bone. In long-term studies the anchorage proved to be stable and no undesired side effects on the soft tissue were observed. This was considered to justify experimental investigation of the possibility of using titanium appliances for bridging long bone defects and stabilising defective jaw bones. Accordingly we carried out a series of experiments with partial resection of the mandible and tibia of the dog followed by reconstruction with transplants of marrow and trabecular bone reinforced with titanium framework. The results were good with satisfactory new formation of bone and without any demonstrable undesired tissue reaction to the implanted metal (Bränemark, Lindström, Hallén, Breine & Hanson, 1969).

At the same time we studied microscopically in vivo the microvascular anatomy and physiology with the aid of a titanium chamber implanted subcutaneously in twin pedicled skin tubes in homo (Bränemark, Aspegren & Breine, 1964 a; Bränemark, 1969 a). Here, too, the titanium was found to be practically inert not only when placed in the subcutaneous tissue, but also where the metal projected through the skin, thus at the site where there is liable to occur a direct open communication between the external and internal environments.

The stability of the anchorage of the appliance in the bone, the practically complete absence of undesired tissue reactions and the function of the tissue barrier on perforation of the skin by the implant induced us to try specially designed titanium appliances in the jaw bone in the hope that they would not produce more than a negligible reaction of the gingiva and bone to the implanted material. A reactionless passage of the titanium appliance through the gingiva and a firm anchorage in the skeleton would provide a possibility of fitting permanent dental prostheses, i.e. a method presumably satisfying the biological prerequisites for a long useful life of the prostheses.

**Aims of the present study**

The purpose of this experimental investigation was, above all, to find out which factors are liable to influence the stability of anchorage of an implant and thereby the possibility of successful clinical use of a prosthesis anchored in skeletal tissue. The investigation was thus concerned mainly with the pattern of the early and late reactions to the technical performance of the insertion of an appliance, the nature of the implant, the effect of loading of the appliance and oral hygienic measures.

If a permanent stable anchorage of an artificial denture in a jawbone is desired, the appliance should be anchored directly and not indirectly to bone tissue. This opinion is based on the extensive experience with alloplastic material used in experimental and clinical surgery in reconstruction of the skeleton. For this reason we confined the investigation to intraosseous anchorage.

**Material and methods**

Twelve male dogs, harriers, weighing 20-25 kg and aged 3-4 years were used.

The implant material consisted of titanium (ATi 24 Avesta Jernverk, Sweden). This material was chosen because it had been found to cause practically no tissue reactions when inserted in bone and marrow tissue in dogs and in subcutaneous tissue in homo, as judged by long-term studies with the titanium chamber (see above). The inertness of titanium has been confirmed by inter alia Laing et al. (1967).

The implants were carefully cleaned mechanically and chemically except for some implants early in the investigation and were sterilized before insertion.

The design of the implant was successively improved and, above all, reduced in size in the course of the investigation (Fig. 2). In the beginning we used an arcuated implant that was anchored by a screw passing transversely through the jaw bone, thus an appliance representing an intermediate stage between subperiosteal and intraosseous implants. Good primary stable anchorage was achieved with this type of appliance, but preparation of the tissues for its insertion was time-consuming, it was bulky, and gingivitis and even necrosis were sometimes seen centrally round the implant. Occasionally granulation tissue developed with consequent loosening of the implant. We therefore
Fig. 2. Examples of different types of titanium implants. (a and b) Devices used in the first pilot studies; (c and d) Screw-like fixture devices with struts connected.

tried screwshaped implants buried entirely within the bone. This design was repeatedly modified in the course of the investigation and we finally arrived at a type satisfying the requirements of the anatomy of the jaw bone. This type was also easy to insert, it remained stable and caused no undesired tissue reaction.

This type of implant, which is here called a fixture, consists of a cylindrical titanium screw provided at its distal end with a number of perforations to allow ingrowth of bone tissue (Fig. 2d) and thereby secure firm incorporation in the jaw. In the centre of the head of the screw is a threaded hole for receiving a pin, on which the prosthetic appliance can be screwed.

So far, 90 implants, including 67 screw fixtures, have been inserted. It should be emphasized that the purpose of this investigation was not to devise any particular or clinically applicable type of implant, but, instead, to analyse the biological reactions to implants. In other words, it was not intended to elucidate the long-term prognosis of different types of fixture, but to examine the tissue round the implant at different intervals, solely for the purpose of elucidating injury patterns and mechanisms. This means that the time during which the implants were anchored in the present investigation cannot be used as a basis for numerical evaluation of the prognosis for intraosseously inserted, loaded fixtures, in spite of the fact that in certain cases the implants were allowed to remain in situ for several years (Fig. 3).

All operations were performed under intravenous Nembutal (Abbott, 50 mg/ml) anaesthesia with intubation. The teeth in one half of the upper and/or lower jaw were extracted 3-4 months before insertion of the fixture. In some cases root fragments were left behind after extraction.

The implants were inserted with as gentle a technique as possible, here called the atraumatic technique (Fig. 4). Lingually or palatinally stalked mucoperiosteal flaps were raised, after which the bed for the implant was prepared with special burrs and screw-taps. Care was taken to avoid unnecessary tissue injury by using as little pressure as possible, low r.p.m. and continuous irrigation of the operative field. After the implant had been placed in position the mucoperiosteal flap was sutured back into place so that the area of the implant was sealed off from the oral cavity.

In some cases the tissue was intentionally traumatized during preparation by increasing the pressure applied to the burr, etc. and by reduction of the irrigation. This was done to assess the effect of the operative trauma.

In other cases poor approximation of the mucoperiosteal flap with incomplete sealing of the operative area resulted in subsequent open communication between the oral cavity and the site of the fixture.

After a healing period of 6-8 weeks the upper surface of the implant was exposed by a small incision in the soft tissue, a post designed to receive the prosthesis proper and here called a strut, was screwed to the implant and the mucosa was adapted round the strut. After a further two weeks impressions were made for the manufacture of prostheses in the form of bridges which were afterwards anchored to the strut with screws.

In the beginning we used Vitallium prostheses with broad bases; later the Vitallium bases were provided with acrylic
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The dogs were given an ordinary diet, i.e. canned dog food of soft consistency and, as a rule, no attempts were made to keep the dogs' teeth and bridges clean. This lack of oral hygiene resulted in the occurrence of rests of food, hairs, wood fragments, bacterial plaque, calculus etc. in the junction between the prosthesis and the gingiva and round the struts projecting through the gingiva. Gingivitis of varying degree was observed. After modification of the strut it was found that an uneven surface resulted in a more pronounced gingivitis. With the introduction of local oral hygiene measures the gingivitis soon disappeared and the mucosa in the region round the ginvival passage of the strut became free of inflammation (Fig. 7b and c). The oral hygienic measures consisted mainly of scraping off hard and soft deposits on the prosthesis and struts and careful brushing.

The reaction of the tissue round the implant and of the oral mucosa beneath the bridges was judged by macroscopic and stereomicroscopic inspection and recorded by close-up colour photography. The hard tissue was judged radiographically and histologically; the soft tissue, histologically. The stability of the anchorage was tested by allowing the animals to load the fixtures, e.g. by chewing bone.

Before removal of the preparation en bloc for histological examination the stability of the anchorage was evaluated. Its resistance to torque was always tested. The tensile strength of the union between the implant and the bone was recorded in only a small number of cases because this method damaged the junction between the tissue and the fixture and thereby reduced the possibilities of analysing this important region.

RESULTS
The stability of the anchorage of the implants was excellent. This was apparent from, among other things, the fact that in certain cases where loading had been maximal, e.g. chewing of bones, fractures occurred in the strut or prosthetic appliance. Nevertheless, however, the anchorage of the fixture in the jaw bone, remained intact. This means...
then that the mechanical strength of the anchorage was stronger than the strength of the strut and the prosthetic material.

The tensile strength measured varied from 30 to 100 kp, the highest value being recorded for mandibular fixtures. Rotational stability was found to be more than 75 kp for the entire circumference of the bone and more than 75 kp even for half of the circumference of the bone (Fig. 5). Fixtures completely anchored in bone could not be removed by conventional methods for extraction of teeth. Here too, even when the tissue round half of the circumference of the appliance had been removed, the fixture had to be luxated out of its position with considerable force before the anchorage broke down.

In those cases where the traumatic operative technique was used and in some of those where there was primary communication between the site of insertion and the oral cavity, the fixtures were more or less mobile. This mobility increased on loading of the fixture.

In certain cases the loading of the fixtures was increased further by giving the appliance the form of an extended bridge without support for one or more molars during chewing (see Fig. 6). In these cases, then, the masticatory pressure was applied to the fixtures via a leverage system. Even in cases of fixtures that had for 5 years been loaded ad libitum in this way the adjacent jaw bone was clinically and roentgenologically intact.

As a rule, 2 or 3 fixtures were placed in a straight line in each half of the jaw (Fig. 6 a). Since the teeth of the dog during chewing perform a shearing movement, the molars of the upper jaw sliding with their palatinal surfaces along the buccal surfaces of the lower molars, this geometric arrangement resulted in the fixtures being

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**Fig. 5.** (a and b) Diagrammatic representation of maximum extraction load tolerated by intraosseous implants for vertical load forces (black arrows) and torque (white arrows) showing the situation for both upper and lower jaw in the dog. (c) Schematic illustration of torque applied to implant after the surrounding bone has been removed from half of the circumference of the implant during preparation for histologic analysis. (d) Fixture and strut after extraction in the axial direction. Bone tissue was found round the implant tightly adherent to it, indicating that this bond was stronger than the connection between this bone and the adjacent bone. 21 months. × 5.
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subjected via the bridge to strong lateral forces. But even this did not produce any disturbance of the anchorage of the fixtures.

During regular visual control (macroscopic and stereomicroscopic) of the gingival tissue adjacent to the strut it was found that no signs of gingivitis had developed in those cases where the struts had been cleaned. The mucosa, even that adjacent the strut was normal in colour and consistency. In these cases the gingiva was closely attached to the strut. The mucosa often appeared to be adherent to the metal (Fig. 7 b and c) along that part that was situated in the soft tissue, even in its most marginal parts.

In those cases where the struts had not been cleaned, typical symptoms of gingivitis (Fig. 7 a and colour plate B) appeared with a formation of granulation tissue. After oral hygiene was started, gingivitis healed and the tissue approximated to the strut.

In those cases where the traumatic operation technique had been used or where communication

Fig. 6. (a) Diagram illustrating forces, predominantly lateral of direction acting on bridge supported on 3 and 2 fixtures, respectively, in the lower jaw. The bridge to the right is of the extended type. (b) Extended bridge on two fixtures in situ in lower jaw—loaded part to the left. Arrows indicate position of struts. 64 months.

Fig. 7. Healing of gingival tissues surrounding strut as a result of oral hygienic procedures. (a) Shows the soft debris, hair etc., and gingival reaction before oral hygiene was commenced. 53 months. × 3. (b) After two weeks' oral hygiene. 53 1/4 months. × 3. (c) Biopsy corresponding to (b) illustrating the situation in the tissue. Only a few scattered round cells in the adjacent epithelium and connective tissue. 53 1/2 months. × 30.
Fig. 9. Roentgenogram, taken 46 months after installation of fixtures, loaded for 30 months with extended bridge, illustrating marginal resorption of bone in a case with no oral hygiene measures performed and remaining root remnants close to the fixtures.

After installation, a certain lowering of the horizontal level of the bone, as a rule only little (0.5–1 mm to be compared with the length of the fixture, 7 mm) which ceased after 6–9 months, after which the situation become stationary (Fig. 8).

The bone tissue round fixtures was well approximated and was roentgenographically normal. In those cases where gingivitis had developed with the oral cavity persisted, granulation tissue of hyperplastic character developed. Only in some of the early cases, where the titanium details were not chemically cleaned, was black or grayish slight discoloration of the tissue adjacent the struts observed (Colour plate A, E).

The roentgenological examination of the bone tissue round the fixtures showed, for 3–6 months after installation, a certain lowering of the horizontal level of the bone, as a rule only little (0.5–1 mm to be compared with the length of the fixture, 7 mm) which ceased after 6–9 months, after which the situation become stationary (Fig. 8).

The bone tissue round fixtures was well approximated and was roentgenographically normal. In those cases where gingivitis had developed...
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Fig. 11. Histology showing remodelling of bone, compact and spongy, close to fixtures in lower jaw. (a) Longitudinal section of bone surrounding fixture, in situ for 35 months. × 6. (b) Detail of bone site illustrating the exact adaptation of bone anatomy to the surface of the titanium fixture. 46 months. × 65. (c) Longitudinal section of trabecular bone surrounding fixture in situ for 35 months. Remodelling of bone with formation of a bone capsule and stress-supporting bone lamellae perpendicular to the longitudinal axis of the fixture. × 6. (d) Detail of (c) showing curve-shaped lamellae in bone trabeculae due to loading. Note marrow spaces towards fixture surfaces without any sign of inflammation. × 65.
and persisted for some time, progressive vertical bone resorption was noted (Fig. 9), corresponding to one fourth of the total height of the implant.

Oral hygiene with control of the gingivitis resulted in cessation of this bone resorption, even in those cases where the struts had been cleaned only sporadically. The resorptive process tended to decrease in rate of progression with a sort of equilibrium as a result, i.e. one fourth of the fixture in the bone was exposed, but was covered by granulation tissue.

In cases with initial operative trauma rarefaction of bone tissue was seen close to the fixture.

In cases of primary communication with the oral cavity, vertical resorption progressed and rarefactions occurred in the bone tissue near the fixture.

When the animals had been sacrificed, stereo-
microscopic examination of hard and soft tissues round the fixtures and the struts showed as follows.

When no gingivitis was demonstrable, the soft tissue and the bone tissue were normal and closely approximated to the strut and the fixture. The spongy bone was often condensed near the fixture, enclosing it in a capsule (Colour plate C, D).

In the presence of gingivitis the picture was dominated by granulation tissue with wide tortuous vessels in the soft tissue near the strut but also adjacent the upper part of the fixture corresponding to the resorbed bone tissue.

In those cases where the operative technique had been intentionally traumatizing there was an avascular, tight connective tissue capsule round the fixture, which was thereby separated from the bone. In cases with a primary communication with the oral cavity there was also a connective tissue capsule but, as a rule, it did not enclose the entire fixture, because in certain places, especially in the lower jaw the base part of the fixture was sometimes embedded in bone without any intermediate connective tissue. The tissue round the upper part of the fixture in these cases was of granulation tissue type.

**Histology**

The histological picture of cases without gingivitis was fairly uniform. There was a normal or some-

**Fig. 13.** (a) Detail of bone and marrow tissue which had been facing the titanium surface for 35 months. The moderately active marrow shows no sign of injury. × 114. (b) Marrow, with low hematological activity, in trabecular space, close to the fixture, without any cellular or other indications of inflammation. Note the absence of cells at border of bone, which appears to be at rest. 35 months. × 114.
what thickened mucosa where the epithelium along the strut merged with a fairly collagen-rich connective tissue, at varying distance from the upper surface of the fixture. But in none of the cases did the epithelium reach this level (Fig. 10). In this area there were single round cells, and, sometimes at the level of the gingival margin, small accumulations of round cells, but otherwise no signs of inflammation. The collagen fibrils were regularly arranged and intact.

The bone tissue was normal without signs of abnormal osteolytic or osteogenetic processes. There were no osteoclasts (Fig. 11).

Trabecular bone often showed a capsule-like arrangement of the bone adjacent the fixture (Fig. 12 and colour plate C, D). In compact bone the osteones with Haversian systems and lamellae of bone were remodelled according to the forces to which the bone was exposed. Bone lamellae often had a characteristic position in relation to the threads of the fixture (Fig. 11 c and d). The marrow space often bordered the surface of the fixture, but no inflammatory cells or other signs of tissue reaction were observed in active or inactive bone marrow (Fig. 13).

The condition was similar even in cases with low density bone in the upper jaw (Figs. 14 and 15). Growth of trabecular bone with subsequent remodelling in relation to loading was observed in the cylindrical hollow base of this kind of fixture (Fig. 16).

In cases with gingivitis there was moderate epithelial hyperplasia adjacent to the struts, round cell infiltration and granulation tissue vessels (Fig. 17 a). The collagen fibrils were separated by cellular infiltrates.

The space created by bone resorption between the upper part of the fixture and the bone tissue was filled with granulation tissue (Fig. 17 b).

This inflammatory reaction was sharply defined. The bone tissue immediately adjacent to the border of resorption along the fixture was normal, as was the marrow space. No round cell infiltrates were seen in the bone tissue or marrow spaces (Fig. 17 c).

In cases with a primary open communication...
Colour plate. (A) Fixture with strut in situ in lower jaw after exposing the fixtures by cutting the bone in two halves. Appearance of soft and hard tissues when gingivitis had been counteracted. The slight grayish discoloration at the gingival level is due to titanium deposits (cf. Fig. 19 a and b). 46 months. × 3.

(B) Gingivitis and resorption of bone due to lack of oral hygiene procedures. 20 months. × 3.

(C) Fixture in upper jaw in situ for 32 months, loaded for 16 months. Note intimate contact between fixture and bone. × 6.

(D) Fixture in upper jaw (same as in (C)) removed from bone to illustrate remodelling of bone with formation of bone capsule in the trabecular bone. 32 months. × 6.

(E) Fixture site in lower jaw bone with complete fitting to shape of bone tissue to exterior of fixture. Grayish tinge in gingiva due to titanium fragments as in (A). Fixture in situ for 32 months, loaded for 16 months. × 7.
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there was a loose granulation tissue with numerous round cell infiltrates without any distinct border to the bone tissue, which contained inflammatory cells, especially in the upper part at the site of the fixture. The marrow space contained inflammatory cell infiltrates and showed signs of bone resorption.

In cases with initial operation trauma but primary closure of the flap the entire fixture was intimately enclosed by a well outlined capsule of collagen-rich connective tissue, without round cell infiltrates but with a normal number of vessels. In cases where the prostheses had been loaded the architecture of the connective tissue fibers often resembled that of bone trabeculae after loading. Similar tissue characteristics were found in cases where no initial trauma had been produced but the density of the bone was very low (Fig. 18). The bone tissue outside the connective tissue capsule showed no signs of inflammation or osteolysis. No discoloration of tissue adjacent to the titanium was observed, except for a few early cases (Fig. 19).

The more traumatic the operation had been the more marked were the roentgenological and histological tissue damage and defects. No signs were seen of titanium or titanium oxide invasion in the tissue adjacent the fixture or the strut, except for the early cases referred to above.

COMMENTS AND CONCLUSION

The experimental investigations thus clearly showed that in the dog it is possible to anchor titanium fixtures in both the upper and the lower jaw and to subject them for several years to unlimited load or use without any consequent change in stability and without undesired reaction of the bone or adjacent soft tissue and without epithelium proliferating or invading the intermediate zone between bone and the implant.
Fig. 16. (a) Appearance of cylinder of bone which had completely filled the hollow cylindrical base part of a fixture. Note the protruding bone processes, representing holes in the cylindrical part of the fixture (cf. Figs. 2 c and d). 20 months. $\times 11$. (b) Shows the jawbone at the site for the same fixture after removal of implant. In this half of the circumference one of the bone processes (see (a)) was broken on the inner side of the fixture. 20 months. $\times 4$. (c) Longitudinal section of bone plug shown in Fig. (a). Note the architecture of the trabeculae, forming a bony shell, with stabilising bridges. 20 months. $\times 22$. (d) Detail of (c) showing normal marrow and bone tissue without signs of tissue injury. 20 months. $\times 90$. 
Fig. 17. (a) Border zone at level of junction between fixture and strut. In this case a pronounced gingivitis was present, resulting in tissue injury, as indicated by round cell infiltration and bone resorption at upper part of fixture. 48 months. ×19. (b) Shows detail of transition between epithelium and connective tissue towards the surface of the strut. Note horizontal termination of round cell infiltrates. 48 months. ×56. (c) Detail of bone bordering connective tissue, without signs of resorption or inflammation. There are no osteoclasts or osteoblasts, indicating normal turnover and architecture of the bone. 48 months. ×130.
Fig. 18. (a) Longitudinal section of fixture site in upper jaw showing incomplete formation of bone capsule around fixture in trabecular bone with extremely low density of bone, 3 months. × 7. (b) Detail of connective tissue in the low cellular type of bone with bone base and threads towards fixture, 3 months. × 130.
Attempts are now being made to explore the applicability of the results of this experimental investigation in human prosthodontics. The observations allow the following conclusions regarding the factors determining the fate of the implant.

1. Inert, mechanically and chemically clean implant.
2. Implant size small enough to allow complete embedding in bone.
3. Atraumatic preparation of the bed for the implant.
4. Primary closure of the fixture site from the oral cavity until the barrier function of the tissue has been recovered after the operation. This biological barrier (Fig. 20) is formed by approximation of hard and soft tissues to the implant.
5. Loading of the implant via a prosthesis results in remodelling of the jaw bone.
6. Gingivitis with formation of inflammatory granulation tissue should not be allowed to develop or to persist.

Fig. 20. Diagram showing crucial points and tissue regions for: maintenance of integrity of barriers, maintenance of the stability of the connection between the bone and the implant and separation of external from internal environments. Black arrow denotes zone of external mucoperiostal barrier facing surface of the strut. White arrows indicate different critical levels of contact between tissue and implant.

References


