A COMPARATIVE STUDY OF IMPLANTED METALS IN THE SHEEP.

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PRECIS

The transmandibular implant (TMI) has been developed in Holland by Dr. Hans Bosker (Bosker, 1986). Whilst clinical trials in humans have shown extremely good results, with a 97% success rate after five years being quoted in Dutch studies (Bosker and van Dijk, 1983), no histological evaluation of responses of the body to the material has been performed. The objectives of the present investigation were:

1. to develop an animal model for use in evaluating the transmandibular implant.

2. to establish a reproducible method for preparation of sections containing bone and metal.

3. to compare the tissue responses to the individual metals contained in the gold alloy currently used in the manufacture of the transmandibular implant and a high silver content alloy, which has been proposed as an alternative cheaper material.

4. to study the surface characteristics of the implanted metals by scanning electron microscopy.

Merino wethers were used as the experimental animals. Solid cylinders of seven test materials (gold alloy, Dentozyl®, gold, platinum, palladium, silver and copper) were implanted in the mandibles of sheep. Animals were sacrificed after four weeks and thirteen weeks in accordance with the FDI criteria for evaluation of the biocompatibilty of implanted materials. A total of twelve sheep was used. Each mandible was divided into pieces containing one implant, and the specimens processed according to one of the following techniques:

1. after decalcification of the specimens, the implants were removed and the surface characteristics determined by scanning electron microscopy. Any deposits on the metal surface were further identified using electron microprobe analysis. The decalcified sections were processed for optical microscopy with serial sections being stained with (a) haematoxylin and eosin or (b) trichrome. Examination criteria included the presence or absence of inflammation around the implant, and the nature of the interface of the tissue and metal.

2. 50μ thick undecalcified sections were prepared for optical microscopy and examined both before staining and after staining with a modified trichrome stain. Examination criteria were similar to those in (1).

The results of these investigations indicate that:

1. With the exception of copper, all implanted metals appeared to be well tolerated by the tissues, as evidenced by a lack of inflammation, fibrous connective tissue encapsulation and at least focal bone reactivity in the area of the implants. The observed responses of the tissues to copper, namely an intense inflammatory reaction and abscess formation are in agreement with the findings of Venable et al. (1937) and those of McNamara and Williams (1982b). The responses of the tissues to the silver implants in the present study were not as marked as those shown by Pudenz (1942) or by Keller, Marshall and Kaminski (1984).

2. The remaining metals; gold, platinum and palladium, and the two alloys all demonstrated evidence of biotolerance as evidenced by a lack of inflammation, and the formation of fibrous connective tissue

around the implants. A fibrous capsule formed in the medullary portion of the mandible around all of these metals; however, it was thinner and less well-defined than around the copper and silver. These findings are in agreement with those of Zander (1959) and Smith (1982) in relation to gold, and those of Nagem-Filho et al. (1975) in relation to the gold alloy.

3. The cortical bone demonstrated evidence of at least focal remodelling around all implants. With the exception of copper, most specimens exhibited some evidence of close bone/metal apposition in both time periods, but the general pattern observed was that of a layer of fibrous connective tissue of variable thickness interposed between the implant and the cortical bone.

4. Bone did not tend to form close to the implants in the medullary portion of the mandible unless bony trabeculae were pre-existent adjacent to the implants.

5. Only copper and silver exhibited corrosion when examined by scanning electron microscopy. The remaining five metals appeared to be corrosion resistant. These findings are in agreement with those of Pudenz (1942), Seltzer et al. (1972) and McNamara and Williams (1982a).

6. The sheep was a relatively easy animal to handle with respect to anaesthesia and surgery, with no special techniques or instruments required. It is suggested that the sheep could be used as an alternative animal to monkeys and dogs for implantation studies. The particular area of the mandible of the sheep chosen for this study was in

retrospect not ideal in that very little cancellous bone existed; the medullary contents were mainly fibro-adipose tissue. It is suggested that future studies should perhaps concentrate on implantation only in cortical bone.

7. Under the implantation conditions used in this study, there would appear to be no difference in the tissue responses to the Dentozyl® and the gold alloy.

I should like to dedicate this small work to my father and late mother, in recognition of the encouragement and incentive to study that they have always given me. No opportunities to further my knowledge and broaden my horizons were denied me; for this I thank them.

DECLARATION

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Dental Surgery of the University of Adelaide. Candidature for the degree was satisfied by obtaining the Honours degree of Bachelor of Science in Dentistry (BScDent[Hons]) in 1984.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and, to the best of my knowledge, contains no material previously published or written by another person, except where due reference has been made in the text.

Permission is granted by the author for loan or photocopying of this thesis.

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INTRODUCTION

Throughout the world there is widespread use of surgical implants; in orthopaedic surgery, total hip replacements are now commonplace, as are fracture fixation plates; in cardiology, cardiac pacemakers are implanted; and in the dental and oral surgical field the use of implants is becoming more widespread. A small number of patients can be rehabilitated with implants to reconstruct facial appearances after extensive loss of tissue, perhaps after surgery for malignancies; but it is with a more endemic problem that most dental implantology is concerned; to rehabilitate the patients who have difficulty wearing dentures, in particular a full lower denture.

Many different designs of implants made from various materials have been tried: a few remain in use. A review of the literature regarding implant designs and materials is presented in the first part of this thesis. Implantology has evolved very much as a clinical subject; much of the design and use of implants has developed upon clinical evaluation rather than on controlled scientific assessment. This may, in part, explain the varying results reported for the many different designs and techniques. With the possible exception of the Brånemark implant (Brånemark et al., 1977), very little controlled scientific assessment appears to have been performed on implants, although newer techniques, such as finite stress analysis (Vajda and Fung, 1979; Cook et al., 1982) are being used to evaluate new designs.

The transmandibular implant of Bosker is one of the most recent implants to be described in the literature. Clinical results seem promising for this particular design, but little attention has been paid to the nature

of the host tissue response to the implant. Bosker himself expects bone to remodel into a direct relationship with the implant after placement, because the material from which it is constructed is classified by him as being bioinert. The nature of this interface is of importance in the dissipation of forces when the implant is loaded in mastication.

The objectives of the present investigation were:

1. to develop an animal model for use in evaluating the transmandibular implant.

2. to compare the tissue responses to the constituent metals of the gold alloy currently used for the manufacture of the Bosker implant and a proposed alternative alloy, Dentozyl®, with the two alloys.

3. to study the surface characteristics of the implanted metals by scanning electron microscopy.

Solid cylinders of seven test metals (platinum, palladium, gold, silver, copper, Dentozyl®, and the gold alloy) were implanted in the mandibles of mature Merino wethers. Animals were sacrified after four weeks and thirteen weeks in accordance with the FDI criteria for the evaluation of the biocompatibilty of implanted materials. A total of twelve sheep were used.

Each mandible was divided into pieces containing one implant, and the specimens processed according to one of the following techniques:

1. after decalcification of the specimens, the implants were removed and the surface characteristics determined by scanning electron microscopy. Any deposits on the metal surface were further

identified using electron microprobe analysis. The decalcified sections were processed for optical microscopy with serial sections being stained with (a) haematoxylin and eosin or (b) trichrome. Examination criteria included the presence or absence of inflammation around the implant, and the nature of the interface of the tissue and metal.

2. 50μ thick undecalcified sections were prepared for optical microscopy and examined both before staining and after staining with a modified trichrome stain. Examination criteria were similar to those in (1).

In addition, the two alloys used in this study were subjected to quantitative analysis, to check their compositions with those stated by the manufacturer.

CHAPTER 1 ORAL IMPLANTS

1.1 INTRODUCTION

Following the extraction of teeth, atrophy of the human alveolar process occurs to varying degrees (Atwood, 1971, 1979). The edentulous ridge which was initially high and broad becomes lower and narrower due to bone resorption (Carlsson and Persson, 1967). The buccal sulcus becomes shallower and eventually the circumoral muscle attachments are situated at the crest of the ridge. Stability of a denture then becomes a problem. This is especially so in the mandible where adequate retention is difficult to obtain even in normal circumstances. In a recent study, Brånemark et al. (1977) estimated that more than 75% of edentulous patients lived with a permanent fear of their dentures loosening or falling out. Only 3% of his sample denied any such fears.

Currently there are three main methods of improving the denture-bearing area for patients who are unable to wear a conventional denture because of atrophy of the bone, trauma or for psychological reasons. These methods are;

1 **Relative augmentation of the ridge.**
This can be achieved either by deepening the buccal sulcus with a vestibuloplasty and soft tissue graft (for example, Tideman, 1972; Huybers et al., 1985), or, in the mandible, by lowering the floor of the mouth (Obwegeser, 1958). A minimum height of 15mm of bone in the midline is required for these procedures (Härle, 1975).

2 **Absolute augmentation of the denture bearing area.**
This can be achieved using osteotomies without bone grafts (for example the visor osteotomy of Härle [1975]), or with bone grafts (for example the

interposed bone graft augmentation of Stoelinga et al. [1978]). More recently, augmentation techniques using injected calcium hydroxylapatite have been described in the literature with promising results (Baker et al., 1979; Kent et al., 1982; Griffiths, 1985; Härle, 1985). Hydroxylapatite has also been described for use in conjunction with bone grafts (Mercier and Zeltser, 1986). While osteotomies are usually confined to the mandible; it would appear that hydroxylapatite can be used in both jaws.

3 Oral implants.

An oral implant is an alloplastic device inserted in or upon the jawbones, teeth or mucosa, usually to aid retention and stabilisation of a prosthodontic appliance (von Fraunhofer, 1975). There are two principal types of implant used in oral and dental surgery; the totally buried, such as the fracture plate, and the semi-buried, which penetrates the oral mucosa (Hobkirk, 1983). The semi-buried devices are invariably used for retention of dentures, and it is with these implants that this review of the literature is concerned.

There are several ways of classifying the semi-buried oral implants; for example, on the basis of shape (Babbush, 1980); material (Swart, cited by Bosker, 1986), and function (Bosker, 1986). Manski (1982) presented a classification based on the method of anchorage. A modified form of this classification (Table 1.1) will be used in this review of the literature.

SUBPERIOSTEAL	
ENDOSSEOUS	- screws, coils and spirals - blade-vent and anchor - tooth replacement - osseointegrated
TRANSOSTEAL	- mandibular staple bone plate - transmandibular implant
MISCELLANEOUS	- intramucosal inserts - endodontic stabilizers

Table 1.1 Classification of the types of dental implants (modified from Manski, 1982).

1.2 THE SUBPERIOSTEAL IMPLANT

The concept of the subperiosteal implant was first introduced to the European literature by Dahl in 1943 (Williams, 1981a), and to the American literature by Goldberg and Gershkoff in 1949. The implant consists of a substructure, placed subperiosteally over the superior surface of the mandible, and a superstructure, usually containing four abutments, penetrating the mucosa. The overdenture, with stable retentive attachments, can be seated on the superstructure, (Mentag, 1980). The framework of the implant usually is cast in a chrome-cobalt alloy. Various coatings of, for example, carbon have been applied to enhance biocompatibility (Leake et

al., 1979; Mentag, 1979).

A subperiosteal implant can be used for stabilising full dentures, as a means of providing abutments for fixed bridges, and for restoration of a resected mandible (Mentag, 1979). It is best placed in the mandible, overlying very dense alveolar or cortical bone (Linkow and Mahler, 1977). This implies that the subperiosteal implant is more suited to placement in the mandible than the maxilla. Implants for use in the maxilla have been described (Barandes et al., 1974; Hahn, 1979; Linkow, 1980a), but most designs are for mandibular usage (Goldberg and Gershkoff, 1949; Lew, 1973; Linkow, 1973; Weiss and Judy, 1974; Bodine, 1978; Mentag, 1979, 1980).

The subperiosteal implant is designed separately for each individual, with the design of the framework conforming to certain guidelines (Williams, 1981a). Early designs varied from narrow metal strips held in place by screws or circumferential wires, to cast metal frameworks of varied configuration. Current designs of the substructure are usually held in place by accuracy of fit and fibromucosal attachment of the tissue (Bodine and Mohammed, 1970; Linkow, 1974; Weiss and Judy, 1974; Bodine, Melrose and Grenoble, 1976; Linkow and Mahler, 1977; Bodine, 1978). Linkow (1984) described a modification of the substructure; retention was enhanced by the addition of fenestrations, into which tissue ingrowth could occur.

Modern designs of subperiosteal implants may cover the whole of the mandible or maxilla, or may provide a terminal abutment for edentulous areas. The framework needs to rest on areas such as the external oblique ridge and the buccal cortical plate, which can bear the implact of these stresses (Weiss and Judy, 1974). In 1978, de Hernandez and Bodine demonstrated that a

subperiosteal implant-borne denture could tolerate twice the masticatory force of a non implant-borne denture. Boucher (1976) studied the pressure created by the implant on bone, and postulated that if forces could be dissipated or absorbed within the implant, bone resorption would be reduced; a factor which is incorporated in the design of other types of implants.

Weiss and Judy (1974) and Adams and Williams (1985) described in detail a two stage technique for the placement of the subperiosteal implant. The implant can either be inserted in a second procedure on the same day, or by waiting for complete healing some four to six weeks later, and then inserted.

Prior to the Harvard Conference in 1978, many papers were published citing excellent clinical results for subperiosteal implants. Bodine (1974) stated that a patient had a 96% chance of having a successful implant after five years. This decreased to 67% after ten years and 52% after sixteen years. In a review of 1434 cases, Mack (1975) stated that 163 implants had had to be removed; although he did not state how long the implants had been in place prior to removal. An attempt to standardise the survival criteria of subperiosteal implants was made at the Harvard Conference. At this convention, Natiella (1980a) collected 143 case reports of implants which had been in place for periods ranging from three months to nineteen years. Of the 143, 38 had been removed, mainly due to bone exposure and acute or chronic inflammation. Other studies collected but not collated at the conference gave a higher incidence of failure. Yurkatas (1967) quoted a survival rate of only 5% in 1048 implants. Natiella (1980a) reviewed the complications associated with subperiosteal implants. Complications included acute swelling, infection, exposure of the framework and damage to the mental

nerves, but it was not always necessary to remove the implant.

Bodine and Yanase (1980) attempted to standardise their results for success of subperiosteal implants. Since their technique had remained unaltered since 1974, they evaluated their cases annually with standardised criteria. They quoted a varying complication rate, but quoted a 100% survival rate after four years in a series of thirty-five patients. At the same conference, Goldberg (1980) quoted a survival rate of 46% after five years for subperiosteal implants placed by him. However, a direct comparison between the two papers is not possible because different indications for removal were used by the two groups.

Since the 1978 Harvard Conference, reports on the subperiosteal implant have occurred less frequently in the literature, possibly due to the development of other techniques for achieving denture stabilisation.

Animal research using subperiosteal implants has been performed, and the results of some of these studies are shown in Table 1.2. Comparison of the results are difficult due to the differing techniques and different animals used. Most authorities however did agree that fibrous connective tissue is most often found enveloping the implant.

Details of tissue reactions to subperiosteal implants in humans are rare. Bodine and Mohammed (1970) and Bodine et al. (1976) reported the case of a patient who had died with a subperiosteal implant in place. They found fibrous tissue surrounding the implant and also observed that the bone had a tendency to grow over the metal framework. This bone was vital but inactive.

Author	Year	Type of implant	Animal model
Armitage et al.	1971	Endosseous	Monkeys
Bodine	1955	Subperiosteal	Dogs
Boucher & Surwillo	1968	Subperiosteal	Rabbits and dogs
Branemark et al.	1969	Endosseous	Dogs
Brown	1969	Endosseous	Monkeys
Capozzi	1954	Subperiosteal	Dogs
Christensen	1970	Subperiosteal	Dogs
Criello & Toldo	1958	Subperiosteal	Dogs
Cobb	1960	Subperiosteal	Dogs
Driskell	1972	Endosseous	Monkeys
Gross & Gold	1957	Subperiosteal	Dogs
Hamner	1970	Endosseous	Baboons
Hamner & Reed	1972	Endosseous	Baboons
Harris	1969	Endosseous	Rabbits
Hegedus & Inke	1957	Endosseous	Dogs
Herschfus	1954	Subperiosteal	Dogs
Herschfus	1955	Subperiosteal	Dogs
Herschfus	1958	Subperiosteal	Dogs
Hodosh et al.	1964	Endosseous	Dogs, monkeys, baboons
Hodosh et al.	1967	Endosseous	Baboons
Hodosh et al.	1968	Endosseous	Baboons
Hoppe	1969	Subperiosteal	Dogs
Johnson	1963	Endosseous	Rats
Kaketa & Suzuki	1969	Endosseous	Dogs
Kent	1972	Endosseous	Monkeys
Mack	1961	Subperiosteal	Monkeys
Mack	1968	Subperiosteal	Monkeys
Meenaghan	1975	Endosseous	Monkeys
Muratori	1968	Endosseous	Monkeys
Natiella et al.	1974	Endosseous	Monkeys
Newman & Van Huysen	1954	Subperiosteal	Dogs
Nichols	1959	Subperiosteal	Monkeys
Pasqualini	1962	Various	Dogs
Reichenbach & Naucke	1955	Subperiosteal	Dogs
Seidenberg & Lord	1963	Endosseous	Dogs
Sinclair-Hall	1964	Endosseous	Dogs
Small & Kobernick	1969	Endosseous	Dogs
Strock & Strock	1943	Endosseous	Dogs
Terry & Boucher	1963	Endosseous	Dogs
Young	1972	Endosseous	Dogs
Waerhaug	1956	Endosseous	Dogs
Waerhaug & Loe	1958	Endosseous	Dogs

Table 1.2 Table showing some of the animal experiments performed, with different types of implants and different animal models.

1.3 ENDOSSEOUS DENTAL IMPLANTS

The concept of the endosseous dental implant has been known for many years: the pre-Colombian Indians used stones to replace missing teeth. Greenfield, in 1913, used hollow lattice cylinders of iridio-platinum in the shape of dental roots and Tomkins was using porcelain teeth in 1921 (Morse, 1977). By definition, an endosseous implant penetrates bone, one part being fixed to the alveolar bone and the other part being located in the oral cavity where it supports a prosthesis.

A wide variety of endosseous implant designs using different materials has been conceived and tested (Grenoble and Voss, 1976). The main categories are shown in Table 1.1.

a) Screw, coil and spiral implants

In the modern literature, Formiggini (1947, cited by Williams, 1981a)) was perhaps the first to describe an endosseous implant. He described a spiral shaped implant which screwed directly into the bone. This design was later modified and described in the French literature by Cherchève in 1962 (cited by Linkow, 1970a). Cherchève's design, made from a cobalt-chrome alloy, consisted of a double helical spiral at the apical end of the intra-osseous portion buried below the alveolar crest, and a narrower solid square shaft at its extension into the oral cavity. Both these designs required bone to be surgically removed and then tapped to receive the implant. All were made of metal, usually cobalt-chrome alloys, stainless steel or titanium, and all depended on achieving an adequate depth in the bone for retention.

A slightly different design was described by Scialom in 1962, (cited by Williams, 1981a). His implant used three tantalum pins inserted in different directions to give a

tripodal abutment which was held together by cold-cured acrylic resin. Because of the divergent path of the pins, sufficient pre-existing bone in bucco-lingual and vertical directions was required for the use of this design.

These designs are now rarely used because of their high early failure rate, due partly to high stresses and poor resistance to lateral forces, and partly to downgrowth of gingival tissue along the implant-tissue interface before bone formation could take place within the open areas of the implant.

b) Blade and anchor implants

Linkow (1970a) studied the tissue responses to screw type endosseous implants and found that implants became encapsulated by connective tissue which he theorised would transmit occlusal forces to the deeper portion of the implant. From this research, Linkow developed the blade-vent endosseous implant (Linkow, 1970a,b,c) for use in narrow alveolar ridges where excessive bone resorption had occurred.

The blade-vent implant consists of a wedge-shaped intra-bony titanium portion incorporating vents, lying within the confines of the alveolar ridge, and either one or two abutment posts protruding from the superficial part of the blade, and joined to it by a narrow neck. The shoulder rests 1 to 2mm below the alveolar crest. The vents in the blade are designed to allow bony ingrowth and hence provide increased retention.

Many investigators in the early 1970's were working along similar lines (Lew, 1970; Roberts and Roberts, 1970; Fagan and Fagan, 1977; Fagan, 1980). Babbush,

Banks and Weigand (1979) made modifications to the blade-vent implant and used pure titanium with a textured cast surface. Cranin and Dennison (1970) fabricated the anchor implant, based on similar principles, but modified to have a much longer intra-bony shaft, designed to increase the amount of bone resorption which had to occur before excessive mobility or exposure of the implant resulted in chronic infection and failure. James and Valantine (1978) further modified this design to a buttressed anchor.

Currently the anchor implant is seldom used, whereas the blade-vent implant still appears to be widely used in the USA, where 90% of all implants placed are of the endosseous type (Weiss, 1982). The implants are available in a variety of designs and sizes, and are placed in a one stage procedure, usually using local analgesia (Linkow, 1980b).

The clinical success rates of endosseous implants were difficult to evaluate prior to the Harvard Conference in 1978, due to the fact that few longitudinal studies had been carried out. Linkow (1974) published the results of a study of 173 patients who had between them a total of 427 blade-vent implants, 246 mandibular and 181 maxillary. Only 12 patients experienced pain, mainly during function. Examination of these patients had revealed deep gingival pockets around the implants, which Linkow attributed to the poor oral hygiene of the patients. No mention was made in this paper of the overall failure rate of the endosseous implants. Cranin, Rabkin and Garfinkel (1977), quoted a 55% success rate for the implants after five years. Smithloff, Fritz and Giansenti (1975) stated that 11 out of a series of 33 implants demonstrated extensive tissue breakdown around the neck, extending into the area beneath the implant shoulder after five years implantation. Asymptomatic

implants with evidence of osseous breakdown and deep pocketing were considered clinically acceptable in all three studies. Most clinical failures appeared to be due to exposure of the implant shoulder and loosening secondary to bone resorption (Natiella et al., 1973). Pericervical saucerization was a common finding in all types of blade implants (Cranin, 1980), with bone loss occurring rapidly in the first six weeks after implant placement, then slowing down (Wie, Larheim and Karlsen, 1979).

c) Tooth replacement implants

This is the simplest type of intra-osseous implant, involving the direct replacement of an extracted tooth with an artificial one. Many materials have been investigated over the years, but most attempts at single tooth replacement have failed because of the very poor stabilization which could be achieved with most materials. Fibrous connective tissue capsules formed around the implants, and eventually epithelial down-growth between the bone and the implant caused their exfoliation (Williams, 1981a).

Hodosh, Shklar and Povar (1970, 1972, 1974, 1975, 1976, 1979) conducted extensive studies of tooth root replica implants. In their early work, conventional poly-methylmethacrylate was used, experimental work being undertaken in baboons as well as in human clinical trials (Hodosh et al., 1970). The advantage of this system was the ease with which the polymer could be made to conform to the shape of the tooth to be replaced. Experiments in baboons showed that these implants were firm and self-supporting after six months, with penetration of collagen bundles into the porous surface. Later modifications included the addition of vitreous carbon to create the surface porosities (Hodosh et al.,

1974, 1975, 1976, 1979). Results from human studies (Hodosh et al., 1977, 1979) showed good stability and periodontal health, although the time period was not stated.

Direct tooth replacement implants have also been made in various ceramics. Hamner, Reed and Hand, (1970), having had little success with polymer implants, studied porous calcium aluminate and reported good stabilization of this material in baboons after one year.

Vitreous carbon has also been used for tooth replacement (Grenoble and Voss, 1977). Currently, this type of implant consists of a hollow stainless steel sleeve open at its occlusal end, and surrounded by vitreous carbon to give a truncated cone morphology. The sleeve receives a keyed post and core to which a prosthesis may be attached. Macroscopic grooving on the root surface provides retention and stabilization, and a microscopic porous texturing provides mechanical interlocking (Grenoble and Voss, 1977). A two stage placement technique is employed, the implant initially being buried for a sufficient period of time to allow bone apposition prior to construction of the prosthesis.

Animal experimentation has shown acceptable clinical results for vitreous carbon implants (Grenoble and Kim, 1973; Stallard, El-Geneidy and Skerman, 1975), especially when splinted to the natural dentition. Minimal amounts of clinical inflammation were reported in the mucosa around the implants.

Assessment of the success of vitreous carbon implants in human clinical trials from the literature is difficult due to the many isolated case reports published. Grenoble and Voss (1977) quoted a failure rate of 25% after two years. Natiella (1980b) at the Harvard

Conference concluded that further studies should be performed and clinical trials undertaken before the tooth replacement implant could be recommended for routine clinical use. Meffert (1983) concluded that the disadvantages of the system were too great and suggested the implant no longer be used.

Another form of tooth replacement implant is that using materials containing calcium phosphate. Early work concentrated on the use of plaster of Paris as a material to fill in periodontal bony defects (for example Alderman, 1969). Levin et al. (1974) and Mors and Kaminski (1975) found a progressive degradation of the plaster and its replacement by calcified tissue after six months when used in periodontal defects.

In 1979, Denissen and de Groot published a report of their experiences using immediate dental root implants made from synthetic dense calcium hydroxylapatite as a means of preserving alveolar bone height. Studies of the implants in animals showed that bone closely adapted itself to the implants and eventually covered them. In human clinical trials, all implants remained in place after one year. It would seem that this type of implant functions as an ankylosed root in maintaining the height of the alveolar ridge. Jarcho et al. (1977) showed that hydroxylapatite implants gradually became invested by bone after six months, a finding supported by Cranin et al. (1986).

d) Osseointegrated implants

Osseointegrated endosseous implants were developed in Sweden by a research team led by P-I. Brånemark. The principle of anchorage in this system, osseointegration, depends upon direct anchorage to the bone of a screw shaped implant of defined finish and geometry. This

principle is different from the anchorage of subperiosteal and most endosseous implants which depend upon non-mineralised connective tissue enveloping the implant for stability. Osseointegration is reportedly achieved and maintained by a gentle surgical installation technique, a long healing time prior to loading, and proper stress distribution in function (Adell et al., 1981). Non-alloyed titanium is used to fabricate the implant. The choice of this metal was based on substantial research by Brånemark's team (Brånemark et al., 1969, 1970; Lundskog, 1972). Further details of the material are given in Chapter 2.

Insertion of implants usually involves the placement of four or six units anterior to the premolar region. The bone is first prepared to receive the implants using special titanium instruments. After placement, the implants are covered by mucosa and left for three to six months to allow healing to take place. After this healing phase, a second procedure uncovers the implant, and abutments of suitable length are screwed into the implant. A conventional bridge is then constructed.

All the patients treated by Brånemark and his co-workers have been carefully followed up by them (Brånemark et al., 1977; Adell et al., 1981; Albrektsson, Jansson and Lekholm, 1986) with clinical and radiographic examination using reproducible techniques (Larheim et al., 1979). Trials have included placement of implants in jaws exhibiting advanced and extreme resorption, with a minority of the patients having only moderate resorption. Certain patients who had extreme resorption required prior reconstruction with bone grafts before implantation (Adell, 1974; Brånemark et al., 1977; Breine, 1980).

Results for the osseointegrated implants to date have

been promising, and more than satisfy the criteria of the Harvard Conference for success. Adell (1983) published clinical trial results for the Brånemark group, where over 4,000 implants had been placed in 600 patients. The results showed a greater than 90% success rate in the mandible, and more than 80% in the maxilla, for periods ranging from one to seventeen years. Complications were noted, mainly due to loss of anchorage function and mucosal problems, and development of hyperplastic tissue and pocket formation around the implants; most of which occurred early after implantation.

Bergman (1983) reported on the clinical results of the Brånemark osseointegrated implant not placed by Brånemark, for the Swedish National Board of Health and Welfare. The results showed a lower survival and succes rate than those quoted by Adell (1983), and the recommendation was that evaluation and placement should be performed by specialists.

1.4 TRANSOSTEAL IMPLANTS

Transosteal implants have been developed for mandibular use, with posts extending through the mandible into the oral cavity from a fixed plate at the lower border of the mandible.

a) The mandibular staple bone plate of Small

The transosteal implant was first described by Small (1975). His implant provides a rigid box frame configuration; a plate on the inferior border of the mandible in the symphyseal region communicates with the oral cavity by means of two threaded transosteal pins. After placement, these posts are left unloaded for a period of six to eight weeks, when a cast gold

superstructure consisting of a connecting bar is made. A tissue-borne prosthesis is attached to the superstructure by means of stress-breaking precision attachments. A varying number of intraosseous screws hold the implant in position. It is necessary for the patient to have at least 9mm of bone height in the parasymphyseal area of the mandible, as measured from a true lateral radiograph of the head. Early designs were fabricated from stainless steel; a titanium alloy containing 6% aluminium and 4% vanadium is currently used (Small, 1980).

In an early survey, Small (1978) analysed the results of 412 mandibular staple bone plates and considered that after six years 372 (90%) were functioning "satisfactorily". Small has been one of the few investigators in the field of implantology to qualify what he meant by "satisfactorily". In this case it was indicative of a firm implant without clinical or radiographic evidence of infection with the patient having a "non-compromised" masticatory ability. Seven per cent were deemed to be in a "fair" condition, (i.e. the implant's function was compromised by infection, loosening and extrusion), but only five implants (3%) had had to be removed, mainly due to fracture of the pins.

Helfrick, Topf and Kaufman (1982) assessed a total of 250 mandibular staple bone plates, apparently along the lines suggested at the Harvard Conference in 1978. Although of these 250, only 62 had been in place for five years, they concluded that the success rate was greater than 75%. The most frequent problem encountered was loosening of the screws followed by extrusion, which they attributed to the fact that the denture was not entirely tissue-borne and that vertical stresses were being transmitted to the implant via the denture.

Another type of transosteal implant was described by Sher et al. in 1979, for use in edentulous mandibles which were not atrophic. The design consisted of a straight screw of threaded Vitallium® which extended from the lower border of the mandible into the oral cavity. Attached to the screw-head was a saddle which in turn was attached to the lower border by means of two countersunk screws. Copings incorporated into the denture clipped over the intra-oral projections. Sher designed this implant in 1966, but results in his paper (1979) were given for 43 patients at the end of one year, when a greater than 90% success rate was reported.

b) The transmandibular implant of Bosker

The transmandibular implant has been developed by H. Bosker, in Groningen, Holland, for use as an alternative to surgical augmentation of the atrophic mandible (Bosker and van Dijk, 1983). The implant serves as a base over which a functional prosthesis can be made without injuring the inferior dental and mental nerves or producing further resorption of the mandible.

The implant is constructed from a gold alloy, the baseplate being cut and pressed, the Dolder bar drawn, and the remaining parts being turned from the metal. The current design is composed of twenty-seven parts (Fig. 1.1) which fit together to form a rigid box-frame construction (Bosker and van Dijk, 1983). The permucosal and supramucosal parts of the implant are highly polished, whereas the intraosseous portions are blasted with alumina to give a surface pore size of approximately 200 μ for the baseplate and 150 μ for the transosseous posts.

In the uniform baseplate, the screw-holes are situated

in the centreline with the exception of the midline screw, which is sited lingually to allow the midline cortical screw to be sited in the internal mental spine. The four threaded transosseous posts penetrate the alveolar crest and the mucoperiosteal tissue between the mental foramina. The posts are supported by, and rigidly attached to, the baseplate, which in turn is tightly anchored to the mandible by five cortical screws. The posts support the intra-oral Dolder bar (Fig. 1.2), so that the implant has a rigid box-frame construction (Figs. 1.3 and 1.4). The retention sleeves for the Dolder bar are incorporated into the fitting surface of an otherwise conventional denture. The composition of the 18 carat gold alloy used in the fabrication of the transmandibular implant is as follows:

gold	70.0%
platinum	5.0%
silver	12.8%
copper	12.2%

(Bosker, 1986).

This gold alloy was used in the initial implants, and no corrosion was reported in an implant which had to be removed two and a half years after insertion for medical reasons (Bosker, 1986).

To prevent a lever action from the masticatory forces on the superstructure during function, the superstructure should be situated directly above the crest of the alveolar ridge. The baseplate has to be adapted to the lower border of the mandible accurately, and rigid fixation of the posts to both the implant and the superstructure is essential. The three medial cortical screws have an endosseous length of 7mm; the lateral screws have an endosseous length of 3mm. The pillar screws are available in a range of sizes. The distance

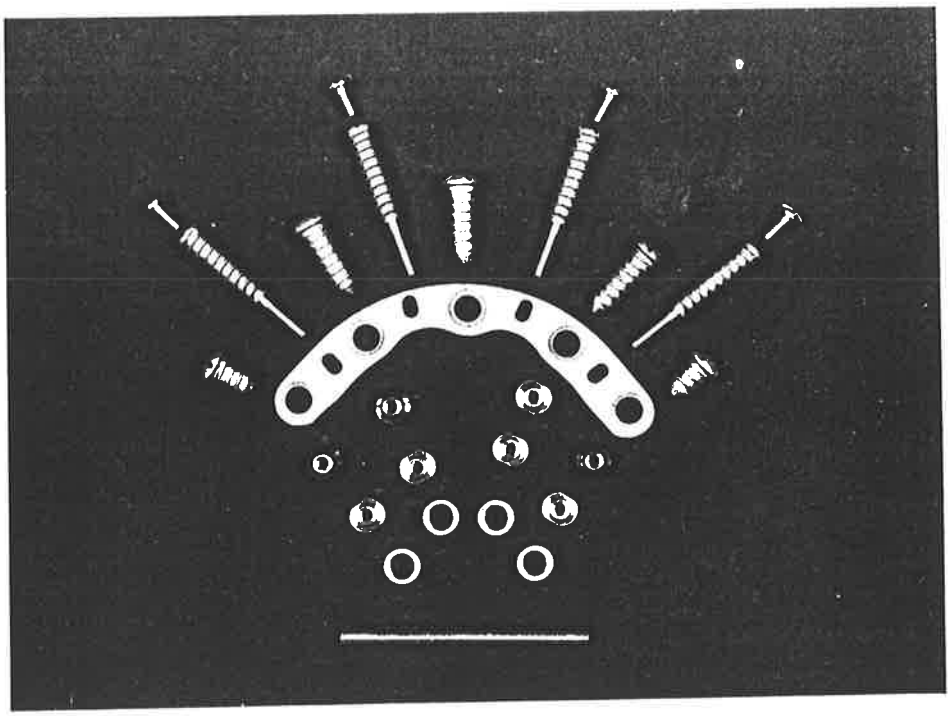


Fig. 1.1 Photograph showing the twenty-seven component parts of the Bosker transmandibular implant.

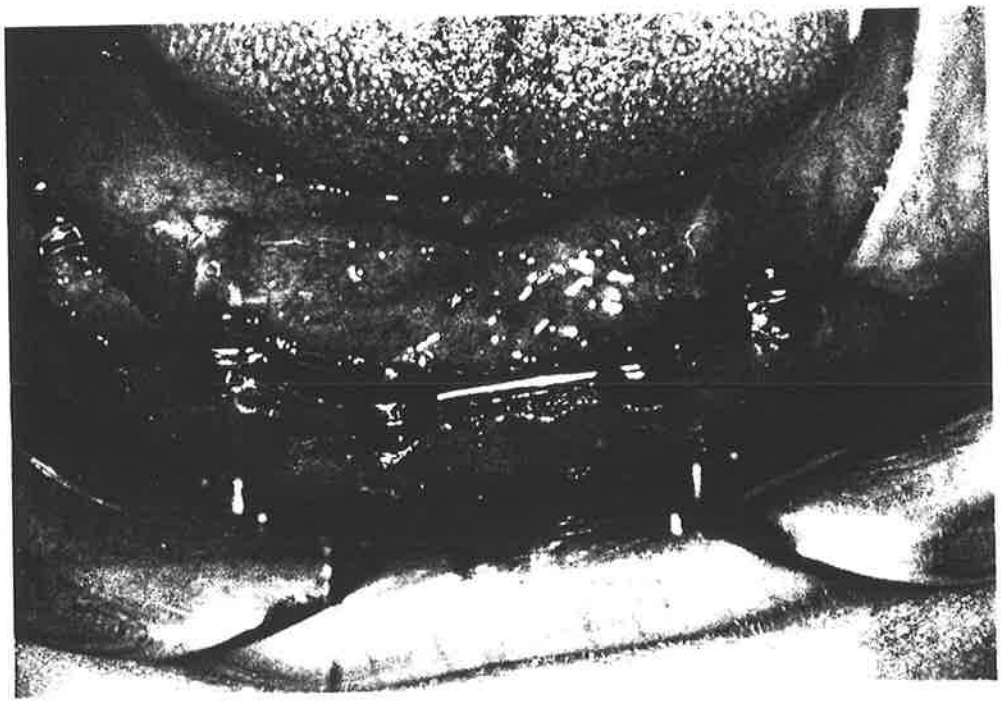


Fig. 1.2 Photograph showing the intra-oral section of the TMI, with the Dolder bar connecting the intra-oral parts of the pillar screws.

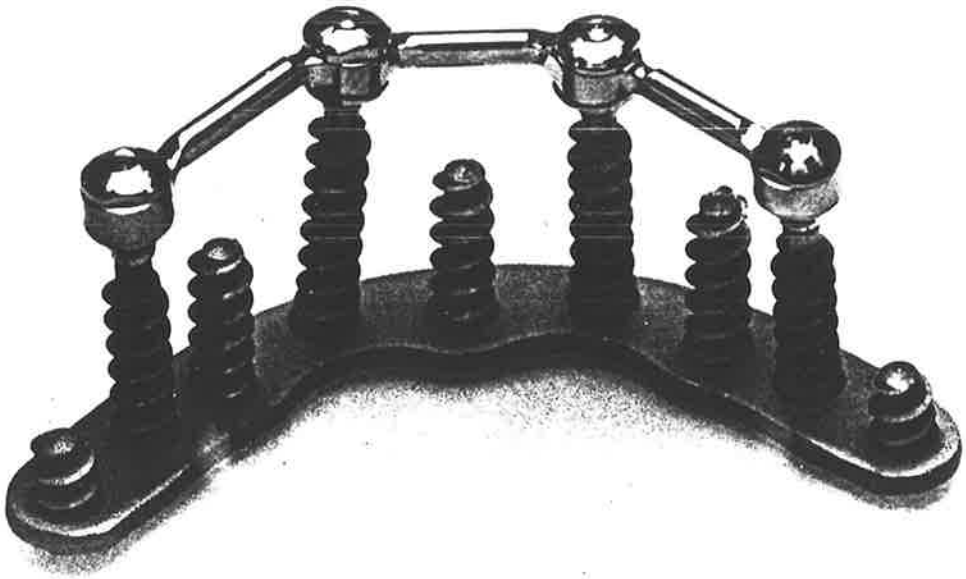


Fig. 1.3 Photograph showing the components of the transmandibular implant assembled.

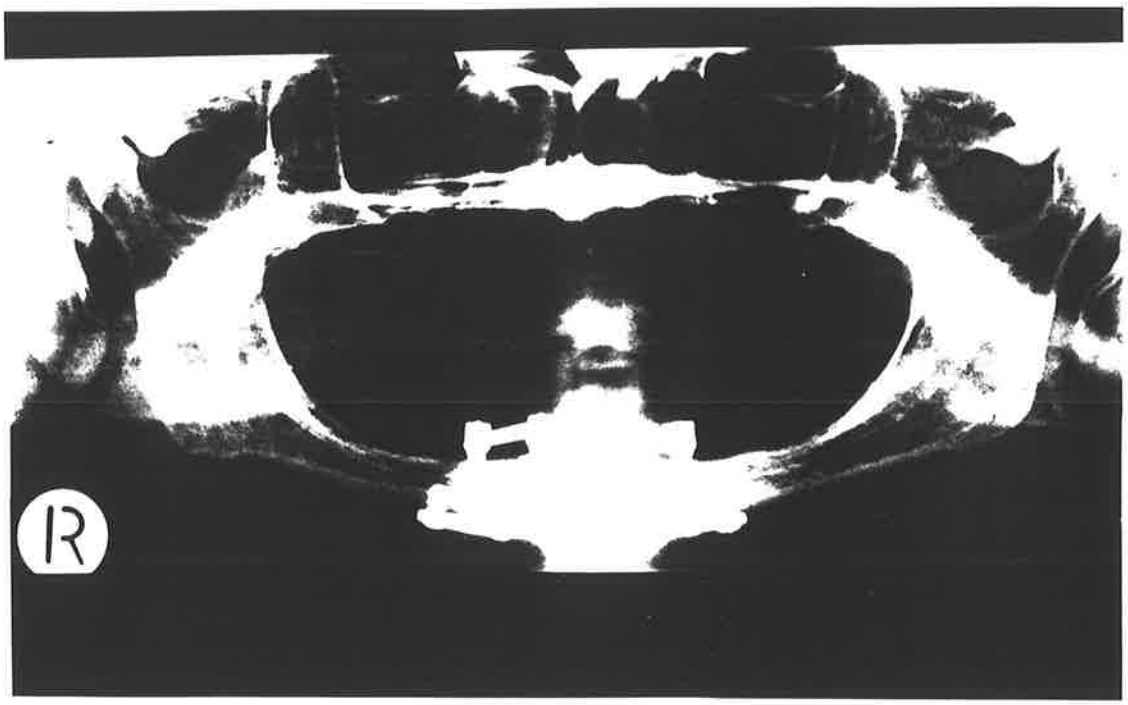


Fig. 1.4 Photograph of an orthopantomograph of a mandible with a transmandibular implant. The box-frame construction is apparent.

between the screw threads is 1.8mm.

After placement, the implant is left unloaded for a period of twelve weeks, to allow for close apposition of bone around the endosseous parts of the implant. A denture is subsequently constructed incorporating a fitting surface to the Dolder bar. During loading, assuming a close apposition of bone to metal exists, there should be no relative motion between the implant and bone. It is postulated that the interlocking between the metal and the bone resulting from the screw design and surface porosities provide a favourable transmission of shear stresses, thus avoiding internal stresses in the bone. The design of the rigid box-frame structure is such that both vertical and lateral forces applied to the Dolder bar are distributed to all posts, thereby providing internal damping.

The "Meccano" type construction of the implant means that should any part of the implant fail, it can be replaced without having to remove and replace the entire implant.

By October, 1985, the current design of the trans-mandibular implant (TMI) had been in use in the Netherlands for eight years. Of twenty-five implants placed in 1978, twenty-four were still functioning well, although several minor adjustments had been made to the implants in that time. One implant had had to be removed due to unrelated psychological problems in the patient (Bosker, 1986).

In an earlier paper, Bosker and van Dijk (1983) reported on a series of ninety-seven implants that had been placed in his clinic in Groningen, Holland since 1978. Of these ninety-seven patients, ninety-five still had their implant in place and functioning well, as

determined by the masticatory ability of the patient and the stability of the prosthesis, *inter alia*. This exceeds the 75% success rate after five years, which is the success criterion determined by the Harvard Conference in 1978.

Post-operative inflammation may develop in the submental region, often with no pathogenic organism being able to be cultured. Bosker and van Dijk (1983) reported a 3% incidence of such a complication; his treatment was aimed at drainage and irrigation of the wound. Fistulae have also been reported in the submental region: Bosker and van Dijk (1983) reported one such case, whereas a study of the Adelaide implant series showed a higher incidence. Radiographs have shown bone resorption around the threaded posts. The author has postulated that this could be due to stripping of the thread of the screw, thereby resulting in the screw working loose and relative movement of the implant-bone interface. Another problem encountered has been the development of gingival hyperplasia around the implant posts (Bosker, 1986).

No unfavourable side effects to the implant have yet been observed in patients. No toxic or allergic reactions have been reported, even though there are reports in the literature of allergies to copper (Frykholm, 1969), and dental gold (Young, 1974; Fregert, Kollander and Poulsen, 1979; Weisenfeld, 1984).

The Bosker implant appears effective in human clinical use, given careful patient selection and meticulous attention to surgical detail (Bosker, 1986). However, to date, no animal experimentation has been performed to determine the nature of the tissue responses to the implant, or the characteristics of the bone to metal interface.

1.5 MISCELLANEOUS

a) Intramucosal inserts

Initially described by Judy and Weiss (1973) in the English literature, intramucosal inerts consist of a titanium stud projecting from the fitting surface of a maxillary denture. The projections fit into receptor sites prepared by removing mucosa with a special bur (Judy and Weiss, 1973; Guaccio, 1980).

b) Endodontic stabilisers

Originally described by Strock and Strock in 1943 (cited by Williams, 1981a), endodontic stabilisers consist of metallic posts protruding through the root canal of a tooth into the periapical bone. They are used in cases where an unfavourable crown to root ratio exists, the post moving the fulcrum of movement deeper into bone, thus stabilising the tooth.

CHAPTER 2 MATERIALS USED FOR THE CONSTRUCTION OF ORAL IMPLANTS

2.1 INTRODUCTION

Records describing the insertion of foreign materials into human tissues are very ancient; the use of sutures being recorded some 2500 years ago (cited by Smith, 1974). Tooth replacements are among the earliest known examples of the use of tissue substitutes for reconstructive and prosthetic purposes. The Etruscans used gold bands and wires to fix and locate artificial teeth; ivory has also been used, as have alloplastic teeth from volunteers. Table 2.1 traces the history of some of the materials used in implants. Table 2.2 shows the materials in current use in dental implantology, some of which are considered in greater detail later in this chapter.

The principles of implants which are partially or completely buried in the tissues of the body became accepted in the late 19th and early 20th century. During the first thirty years of this century, many materials, both natural and synthetic, were used for implants. Early emphasis was more on the mechanical restoration of function than on host acceptability of the material. Much information has been collected from earlier trials by Natiella et al. (1972) and other studies (for example Marziari, 1954), resulting in the delineation of certain modern basic principles for implant construction. A comparison between the characteristics of the materials used in implants is seldom detailed in the literature, and little association and correlation has been made in the past between implant failure and factors such as surface corrosion, stress distribution, and ionic release into the surrounding tissues. An attempt is made in this chapter to review and assess the various materials used in dental implantology.

Year	Reference	Material
B.C.	archeological records	stone and ivory teeth in use in Egypt and China
1500's	Pare	wood, bone and ivory prostheses in use
1565	Petronius	gold plate used to correct cleft palate
1666	Fabricius	use of iron, gold and bronze sutures
1827	Rogers	use of gold wire in fracture fixation
1829	Levert	first recorded study of tissue tolerance to metal
1844	Pancoast	stated that wire sutures cause bone necrosis
1886	Hansmann	internal use of bone plates and screws made from nickel plated steel
1891	Znamenski	porcelain and rubber tooth implants
1891	Gluck	first recorded hip replacement using ivory
1894	Lane	first to use fracture fixation plates that could be left in place permanently
1902	Lambotte	using brass
1907	Haynes	developing chromium-cobalt alloys
1912	O'Neill	using vanadium-steel
1924	Zierold	studied the reaction of bone to metal
1931	Smith-Peterson	stainless steel used in hip fixation
1936	Venable & Stuck	developed Vitallium plates
1940	Kuntsher	used intra-medullary fixation pins made from stainless steel
1943	Moore & Bohlman	first metallic hip replacement using Vitallium
1951	Leventhal	first to describe medical use of pure titanium
1962	Smith	developing Al_2O_3 ceramics
1970	Charnley	combined Vitallium/steel femoral head with high density polyethylene acetabular cap for hip replacement
1970	Brånemark	developing osseointegrated dental implants
1970's		tricalcium phosphates and hydroxyapatites
1983	Bosker	70% gold alloy used for transmandibular implant

Table 2.1 A brief review of some important milestones in the use of materials in medical implants.

METALS AND ALLOYS	- stainless steel
	- cobalt-chromium alloys
	- titanium
	- titanium alloy (Ti-6Al-4V)
	- 70% gold alloy
CERAMICS	- aluminium oxide
	- hydroxyapatite
	- tricalcium phosphate
	- calcium aluminates
CARBONS	- vitreous (glassy) carbon
	- pyrolitic graphite
POLYMERS	- polymethylmethacrylate
	- polytetrafluoroethylene

Table 2.2 Summary of some of the biomaterials used for dental and oral implants.

Before being used for a dental implant, a material should first meet the biocompatibility criteria set down by the Federation Dentaire Internationale (FDI) (Langeland and Cotton, 1979). The choice of an implant material varies according to its application, but can be classified under the three headings of biocompatibility, biofunctionability, and availability (Williams, 1981a).

A material is said to be biocompatible if it is not;

1) toxic
2) allergenic
3) carcinogenic
4) mutagenic
5) harmful to the adjacent tissues
6) disruptive to the normal mechanisms of healing
7) subject to corrosion or resorption (Bosker, 1986);

in other words, if it exists within the physiological environment without adversely affecting the body, or vice versa. This is determined by chemical interactions which take place between the implant materials and the body tissues and fluids, at the tissue-implant interface, and by the body's systemic responses.

A material is biofunctional if the mechanical and physical properties it possesses enable the implant to perform its function. Following the insertion of an implant, there is an initial inflammatory reaction due to the surgical trauma. After this resolves, a variety of tissue growth patterns emerge which are the result of an interaction of implant construction, biomechanics and biocompatibiltity (Osborn and Newesely, 1981). Metals form the optimal end of the continuum with respect to the technical aspects, but the highest degree of biocompatibility is provided by hydroxyapatite, as shown diagrammatically in Fig. 2.1.

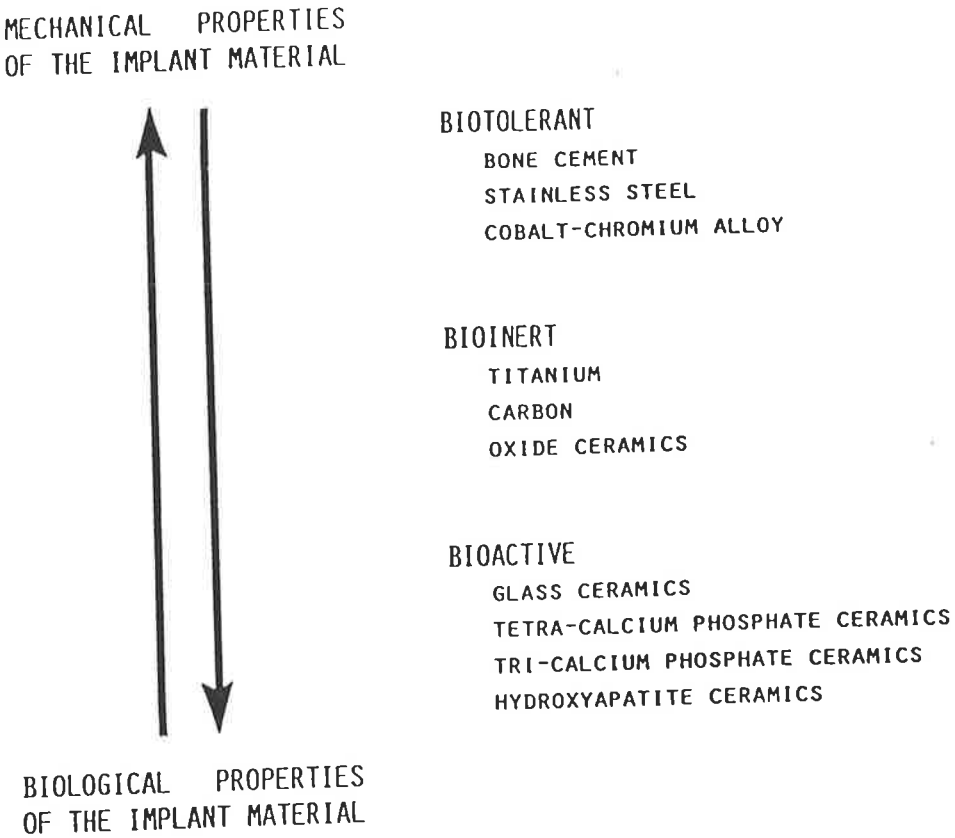


Fig. 2.1 Diagram showing the relationship between the mechanical and biological properties of an implant material, and the tissue responses to it (from Osborn and Newesely, 1981).

2.2 FACTORS AFFECTING TISSUE RESPONSES TO DENTAL IMPLANTS

The tissue reactions to implanted materials are still a matter of considerable controversy. There are many techniques available for evaluating the tissue responses to implants, as reviewed by Cranin (1986). It is outside the scope of this review to consider them all. However, several factors affecting the responses of the tissues to the implant material are important, viz:

a) the nature and morphology of the surface of the implant material
b) the release of cytotoxic ingredients through

corrosion or degradation

c) a shape effect on local tissue metabolism

d) physical effects due to mobility of the implant (Smith, 1974).

All factors may have early or late consequences. Further, local or systemic effects, sensitisation, and allergic reactions may become manifest. The possibility of neoplastic change in the long term must also be considered.

a) Nature and morphology of the surface

The nature or morphology of an implant surface is of major importance, as is its chemical composition, which may be different from the bulk of the implant, having been affected by surface preparation procedures, surface irregularity and contamination, and, in the case of metals, the presence of a surface oxide layer. A scratched or abraded metal surface will have a different reactivity than a smooth or polished surface as a surface oxide layer may be disturbed at sharp edges (Smith, 1974; Jansen et al., 1982).

Cohen (1961) showed that a rough surface texture gave greater stability in bone than did a smooth electro-polished one. It is now well established that bone will infiltrate the pores of an inert porous metal (Bobyn et al., 1980, 1982). Surface porosities of 100μ will permit bony ingrowth, with pores of 150μ allowing Haversian system remodelling (Cameron, Pilliar and McNab, 1976). The pores should be interconnecting and multiple for optimal interlocking of bone with metal (Atkinson and Witt, 1982). The manufacture of porous surfaces on metals is difficult; to obtain a high level of porosity and strength, fine powders must be sintered onto the alloy and the fineness limits the size of the pores

(Galante et al., 1971). During the process of sintering, many of the deep interconnecting pores lose contact with those on the surface, thus limiting bone ingrowth. McKinney, Steflik and Koth (1986) showed that metal implants with a porous surface gave excellent bone adaptation but a poor gingival response. Conversely, a highly polished surface promoted the regeneration of crevicular epithelium around an implant. Thomas (1985) demonstrated that under non-loaded conditions, a bio-compatible implant with a rough surface produced direct bone apposition against the implant; whereas one with a smooth surface resulted in fibrous encapsulation.

A screw-shaped implant provides an increased surface area for interaction between implant and tissue, and can, in this context be viewed as a variant of the surface porous implant system (Homsy, Kent and Hinds, 1973). However, sharp edges may hinder the spread of cells along the surface and thus slow tissue adaptation (Jansen et al., 1982).

The surface energy of an implant has been shown to be an important factor in the nature of the tissue response to an implant, with a high surface energy resulting in a three-fold increase in the number of fibroblastic cells adherent to the surface organic film of various metals (Baier et al., 1984). A high surface energy can be obtained by subjecting an implant to the process of radio frequency discharge, which also sterilises the implant whilst keeping the surface free of organic debris (Baier et al., 1984)

b) Corrosion and degradation

The cytotoxic effects of implant materials may arise from direct chemical reaction of the materials with the fluids and tissues of the host, or components which

become extracted into the surrounding medium, or indirectly through substances which are formed through biodegradation of the implant. Gross chemical effects are seldom seen clinically as materials are chosen for their inertness. Gross reactions have been observed with polymers, especially polymethylmethacrylate, due to the leaching out of residual monomer. The form of the material has also been shown to be a factor; Oppenheimer (1956) showed finely particulate polymers to be more harmful than implants with a larger bulk and surface area.

Direct chemical effects also play a part; Ferguson, Laing and Hodge, (1960) showed that metal ions are present within tissues around all metal implants with a dependent fibrous tissue response. Dobbs and Minski (1980) showed that after hip replacement with cobalt-chromium implants, metal ions, particularly cobalt and chromium, accumulated within adjacent tissue and also in sites distant to the implant, including the liver and kidneys, and were excreted in the urine. Diffusion of ions through a surface oxide film can also occur (Hoar and Mears, 1966), such as is the case with titanium. Little is known of the chemical effects of ceramic implants; ion exchange occurs at the surface, and is the basis of their stability (Williams, 1981a).

The most important aspect of long term tissue reactions to implants is carcinogenesis. Little reference is made to this subject in the dental literature, but it is of major concern in the orthopaedic field, where articulating surfaces may cause particulate matter to be released into the tissues. It has been shown that a number of pure metals, including cobalt and nickel, are carcinogenic in laboratory animals (Williams, 1972). The effects are a consequence of the dissolution of the metal in tissue fluid and its entry into host cells

(Webb, Heath and Hopkins, 1972). Concern has been expressed about the cytotoxicity of vanadium (Rae, 1981).

c) Shape of the implant

Shape also plays a part in the reaction of tissues to an implant. As previously mentioned, particulate matter seems to exert a more irritant effect. Metal particles may be produced during the insertion of an implant. The use of stainless steel wire to immobilise mandibular fractures was shown to lead to the accumulation of particulate stainless steel in the area of the fracture (Simpson and Carter, 1966), but it was not stated whether this was from particles of the drill used to place the wires, or the wires themselves. Sharp edges on an implant may have a stress concentrating effect, thus altering tissue responses. Implants incorporating a shoulder in the design concentrate stress below the shoulder (Soltész et al., 1982). It has not been proved that stress concentration causes bone resorption; but bone resorption around implants has been seen to coincide with areas of stress concentration (Soltész et al., 1982).

d) Physical effects

In addition to the direct chemical effects, a foreign body response to the implant does occur. Usually the body attempts to wall off the implant with a fibrous capsule, the vascularity, cellularity and thickness of which depends on the area, shape and nature of the implant (Homsy, 1970). The mobility of the implant may also increase the formation of connective tissue, and may lead to resorption of bone (Natiella et al., 1972).

2.3 TISSUE RESPONSES TO DENTAL IMPLANTS

Williams (1981a) stated that there are four possible tissue patterns which may be encountered around a dental implant, namely

1) a fibrous capsule with collagen parallel to the implant surface
2) a pseudo periodontal membrane
3) ankylosis
4) epithelial downgrowth

Possible causes of these tissue responses are:

1) local infection
2) pre-existing pathological conditions
3) effects due to surgery
5) the implant acting as a static foreign body
6) the release of particles or solutes from the implant.

Immediately after placement, the stability of an implant depends upon its fit in the surrounding bone. The implant should fit the prepared site as tightly as possible without having to force it into place (Brånemark et al., 1977; Hench and Hench, 1985). After placement, the interface consists of blood and lymph in a disorganised state. A thin multi-layer of natural complex polymers, in particular glycoproteins and proteoglycans form spontaneously on the implant. Such films have been shown to be important in the process of adhesion of cells to an implant (Baier, 1977; Hogan, 1981). The eventual nature of the tissue at the interface with the implant will determine the long term stability of an implant. Most authors prefer to leave an implant unloaded for a period of time to enable the interface to be established (Brånemark et al., 1977; Bosker, 1986).

Most implants eventually become surrounded by a layer of fibrous connective tissue, thought to be the result of the body's response to an inert foreign body (Grenoble and Voss, 1976). Subperiosteal implants depend upon this fibrous tissue for their long term stabilisation. Zarb, Melcher and Smith, (1972) stated that the formation of a fibrous attachment to an implant would simulate the function of the periodontal membrane, and allow the implant to act as a tooth. This has not however been demonstrated clinically. The stability of Brånemark's implant depends upon osseointegration of the implant with the host tissue. Bosker (1986) stated that the stability of his transmandibular implant depended upon a direct bone to metal interface for success and stability.

The nature of the epithelial seal around those parts of an implant protruding through the mucosa has been the subject of much controversy in the past. Histological demonstration of the seal has proved difficult. Direct attachment of hemidesmosomes to implants has been demonstrated by a few authors (James and Schultz, 1974; James, 1980, 1982), and collagen fibres have been reported to insert into the necks of titanium implants (Schroeder et al., 1981). McKinney et al. (1985) stated that a highly polished surface was necessary for the formation of an epithelial seal, and that this could break down if corrosion of the metal occurred.

The presence of an epithelial seal should prevent the ingress of bacteria. Klawitter et al. (1977), in attempting to obtain bony apposition to ceramic implants, experienced complete failure due to bacterial invasion through the porous surface, which had been allowed to extend into the oral cavity. Thus the intra-oral portion of an implant should not have any surface porosities continuous with the intra-osseous

section.

2.4 METALS

a) Stainless steel

Stainless steels, first patented in 1913, were first used in surgical implants in the 1930's (Williams, 1981a). Since then, they have been used extensively in bone surgery, due to their strength, corrosion resistance and high tissue compatibility (Bear, Green and Wentz, 1971). Compositions of stainless steel vary, but all contain chromium, nickel, molybdenum and carbon. The physical properties of 316 stainless steel (the grade most frequently used in surgery) are shown in Table 2.3.

In a saline environment, stainless steel undergoes surface passivation, which prevents further oxidation. Should this surface film break down, the metal exhibits a poor resistance to corrosion (Cahoon and Paxton, 1968; Hughes and Jordan, 1972; Williams and Meachim, 1974).

Although stainless steel was used in oral implants, it is no longer used due to its poor corrosion resistance in the oral cavity, except in the ramus implant (Roberts and Roberts, 1970). It is however, still used for intra-osseous wiring and in orthopaedic surgery, where all the components of an implant are internal.

b) Cobalt-chromium alloys

Initially developed by Haynes in 1907, cobalt-chromium alloys were first used in dentistry in the mid 1930's and shortly afterwards in orthopaedic surgery. The first specific alloy used in dentistry was Vitallium® (Austenal Laboratories Ltd.). It is used today in

METAL OR ALLOY	TENSILE STRENGTH (MPa)	0.2% YIELD STRENGTH (MPa)	ELONGATION AT FRACTURE (%)	HARDNESS (HV)
Wrought stainless steel	500-1480	200-1450	12-40	160
Cast cobalt-chromium	650-700	450-560	4-12	250
Wrought cobalt-chromium	860-1700	300-1275	10-50	440
Wrought titanium	450	275	22	180
Ti-6Al-4V	930	870	10	310
70% gold alloy	880	840	3.5	250
Dentozyl®	740	710	N/A	150* 210†

* value accoriding to NMT (1986)
† value according to Bosker (1986)

Table 2.3 Mechanical properties of some of the metals and alloys used in oral implants.

subperiosteal implants as it can be cast accurately, has an acceptable level of tissue tolerance, and adequate mechanical properties (Table 2.3). It contains mainly cobalt and chromium, with tungsten, carbon and traces of other elements, including nickel. Vitallium® is also available as a wrought metal, with a slightly different composition.

One disadvantage of cobalt-chromium alloys is that they possess a low ductility, and care must be taken in the design of implants if the material is to be cast. Vitallium® has been shown to be compatible with both soft tissue and bone (Fitzpatrick, 1968; Harris and Lossin, 1971).

Oral mucosal responses to these alloys is excellent (Tomlin and Osborn, 1961), and there have been few reported cases of overt tissue reactions; those that have been reported have usually been attributed to the nickel or chromium content of the alloy (Smith, 1982). The Swedish National Board of Health has warned against the use of cast alloys with a nickel content greater than 1% by weight (Bergman, Bergman and Soremark, 1980), due to the risk of sensitivity should the alloy corrode, releasing metal ions into the tissues. Allergic reactions to orthopaedic implants made of cobalt-chromium alloys have also been reported (for example, McKenzie, Aitken and Ridsdill-Smith, 1967; Kubba and Champion, 1975). However, these alloys remain in use in the orthopaedic field.

Corrosion resistance of the cobalt-chromium alloy depends upon surface passivation, with a stable layer of chromium oxide forming. Corrosion does not appear to be a serious problem; isolated case reports are published, and concentrations of the constituent metals have been noticed to increase in tissues adjacent to the metal

(Soremark et al., 1968; Seltzer et al., 1973; Dobbs and Minski, 1980), suggesting that some corrosion or dissolution is occurring.

A direct bone to implant interface has not been reported with cobalt-chromium implants; rather an encapsulation by a relatively thick fibrous membrane occurs. The thickness of this fibrous membrane and the extent of the tissue reaction have been shown to be directly proportional to the amount of corrosion products and the degree of metal dissolution (Laing et al., 1967). Seltzer et al. (1973) demonstrated that cobalt-chromium endodontic pins in dogs became encapsulated by collagen when placed protruding through tooth roots.

c) Titanium

Titanium is a transition element of low specific gravity and high melting point. It was originally used in the chemical and aerospace industries due to its excellent properties, which have also led to its use in implant surgery. Titanium alloys have a wide range of uses in the medical field, including joint replacement, fracture fixation devices and encapsulation of submerged equipment such as cardiac pacemakers (Parr, Gardner and Toth, 1985). It is widely stated to be the material of choice for the construction of most pre-formed dental implants (Hobkirk, 1983). Its properties and uses have been extensively reviewed by Williams (1977a,b; Toth, Parr and Gardner, 1985), and are shown in Table 2.3. The majority of the world's current supply is mined in Australia (Parr et al., 1985).

Elemental titanium can dissolve several other elements to form alloys which possess better mechanical properties than the pure metal. The best properties are obtained when it is alloyed with aluminium and another

transition element, usually vanadium. This generally occurs in a 6%:4% ratio. The alloying elements act as phase stabilisers, with aluminium also serving to increase the strength and decrease the weight of the alloy. After heat treatment, the alloy is light, strong and highly resistant to fatigue and corrosion. Although stiffer than bone, the modulus of elasticity of titanium alloy (Ti-6Al-4V) is closer to bone than any other implant metal, with the exception of pure titanium. This means that stress distribution occurs much more evenly at the metal-bone interface, with the bone and implant flexing to a similar degree, assuming integration has taken place.

Titanium is a highly reactive metal. Within a millisecond of its exposure to air, a 10Å layer of titanium oxide (TiO_2) forms on the surface. This passive layer renders it resistant to corrosion at physiological pH values (Hoar and Mears, 1966; Meachim and Williams, 1973; Solar, Pollack and Korostoff, 1979). Even though the oxide layer does not break down, there is a finite rate of diffusion of titanium through the oxide layer, possibly coupled with abrasion or dissolution of the outer layer, resulting in the release of titanium ions into the tissues. This can give rise to discolouration adjacent to an implant (Williams and Adams, 1976). Even when titanium ions can be demonstrated in the tissues, a mutinucleated giant cell reaction is rarely seen (Williams, 1981a).

The normal level of titanium in human tissues is 50 parts per million (Williams and Meachim, 1974). Values of up to 2000ppm have been observed in tissues around titanium implants (Williams and Meachim, 1974). Stress corrosion is unknown *in vivo*, although it can be induced *in vitro* (Parr et al., 1985). Vanadium may be toxic by binding to the sulphydryl groups of enzymes, although to

date, no adverse or toxic reactions have been reported (Rae, 1981).

If a surface irregularity is present, for example, a scratch or a milling mark, the oxide surface may break down in those areas, as it may also do in the presence of chloride and hydroxyl ions. Bosker (1986) added that fluoride ions may cause pitting corrosion; for this reason he avoided using titanium in his implant, as human plaque and saliva contain fluoride.

Currently, the endosseous blade-vent implants, mandibular staple bone plates and the Brånemark implants are all made of titanium or its alloy. It cannot be used for the subperiosteal implant as titanium cannot be cast.

Histologic studies in animals with titanium blade-vent implants have shown good tolerance by the oral tissues (Armitage et al., 1971), with bone forming within the vents in the implant, and over the shoulder if placed below the alveolar crest.

The concept of osseointegration in titanium oral implants was developed by Brånemark and his workers (1969), to describe the phenomenon of bone growth in direct contact with the implant. One possible reason for this is that the surface oxide layer on both pure titanium and its alloys has a high dielectric constant and is negatively charged. This gives the material a greater affinity for various biomolecules than for water (Meachim and Williams, 1973). Eriksson and Jones (1977) showed that bone with a high negative surface charge had a greater morphogenic activity. Weinstein et al. (1976) showed that bone would grow preferentially in regions of negative electrical potential. The theory of osseo-integration is shown diagrammatically in Fig. 2.2.

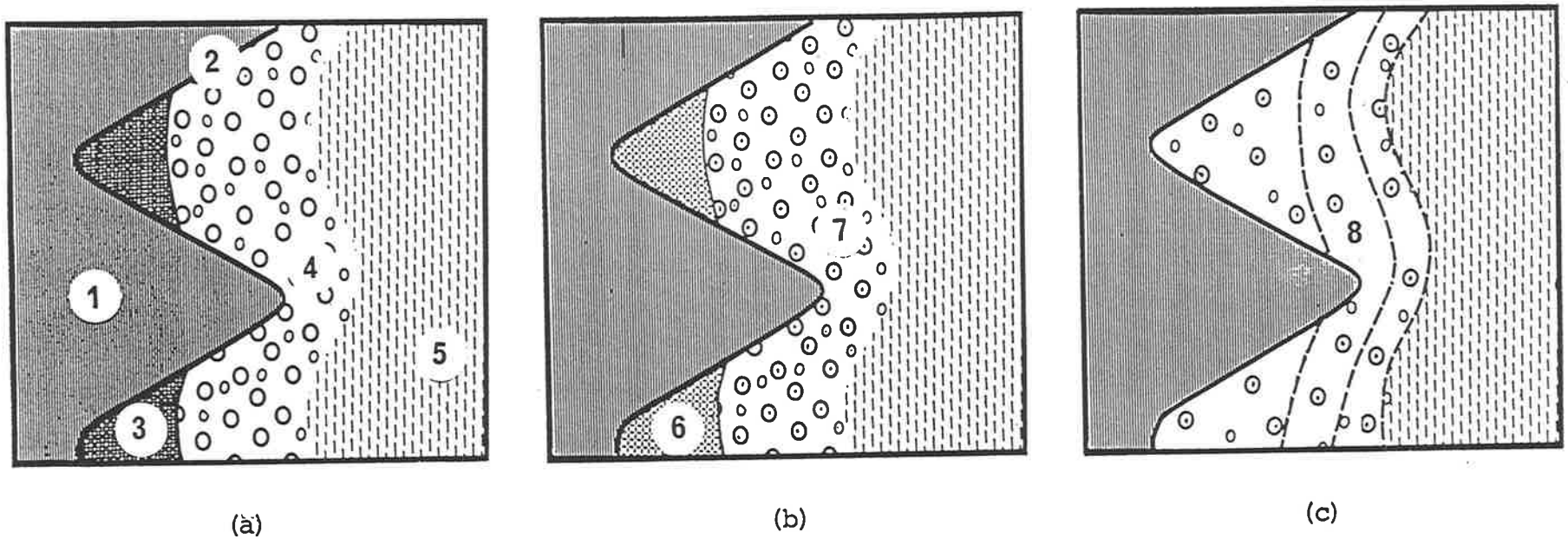


Fig. 2.2 Diagrammatic representation of the theory of osseointegration.

(a) Immediately after placement of an implant (1), a layer of complex organic proteins is adsorbed onto the surface oxide layer (2). Since an exact fit of the implant to the bone cannot be achieved, haematoma formation (3) occurs in the space between the prepared threaded socket and the implant. A zone of bone (4) immediately adjacent to the implant is inevitably damaged during the socket preparation; peripheral to this is the original undamaged bone (5).

(b) During the healing period, the implant is unloaded and the initial haematoma undergoes transformation into callus (6). The damaged bone undergoes revascularisation and repair via demineralisation followed by remineralisation (7).

(c) After healing, vital bone is in contact with the titanium implant. Masticatory loading causes the border zone of bone (8) to remodel.
(Modified from Brånemark, 1983).

The threaded socket indicated in the diagram provides immobilisation immediately after installation. During the initial healing period, the unavoidable haematoma between the bone and the implant is transformed into new bone through callus formation. Bone at the interface which was damaged due to mechanical and thermal trauma is revascularised. After healing, when the implant is loaded, the border zone remodels in response to the masticatory loads (Brånemark, 1983).

Osseointegration seems to be now well established as a concept in the field of oral implantology, and much research has been performed both by Brånemark's team and other laboratories. Most work has been directed at the screw-shaped implant system of Brånemark, where convincing evidence of a direct bone to metal interface has been demonstrated (Hansson, Albrektsson and Brånemark, 1983). It appears that bone lamellae are organised parallel to the superficial surfaces of the screw threads, whereas Haversian systems face the deeper threads (Hansson et al., 1983).

The soft tissue responses to titanium implants have also been studied. Collagen fibres have been reported to insert into the necks of such implants (Schroeder et al., 1981), with functional orientation of the fibres. Epithelium has been thought to attach to the implant from clinical observations, when the sulcus around an implant is probed with a periodontal probe. Several groups of workers have demonstrated the presence of hemidesmosomes and tonofilament attachments between cells and titanium surfaces (Swope and James, 1981; Schroeder et al., 1981; Gould, Brunette and Westbury, 1981, 1984).

d) Precious and semi-precious metals and their alloys

Although pure metals have been used for implants, they have usually failed due to a low intrinsic strength or poor corrosion resistance (Brown, Jacobs and Stark, 1971). During the current literature search, no reports concerning dental implants of pure metals were found; some literature was available concerning implanted metals in various forms, in particular silver cones used for endodontic treatment. Most of the reports are early, as interest in pure metals seems to have waned when the search for better alloys received attention in the 1930's.

The precious metals are considered to be gold and platinum. They are characterised by their relative rarity, high density and resistance to many forms of environmental attack. Only mixtures of oxidising acids and alkaline cyanide solutions are known to attack gold, which is softer and more ductile than the platinum group of metals. Noble metals, including gold and platinum do not form a surface oxide layer (Homsy et al., 1973).

Silver and palladium are semi-precious metals which are less resistant to corrosion than gold and platinum, but can form a protective surface oxide layer. Copper is also reviewed in this section because it is frequently alloyed with the precious and semi-precious metals.

The cytotoxicity of a metal has been shown to be related to its position in the periodic table of the elements (Appendix I). For example, elements in Group II possess strong cytotoxic properties, whereas Groups III, IV and VI do not. Elements in Group I with a lower atomic weight (e.g. copper) possess greater cytotoxicity, tissue irritability and carcinogenicity than do those with higher atomic weights in the same group, e.g. gold. Elements in Group VIII are very bioinert (Kawahara,

1983). To exert an effect on the host, a metal must first be ionised.

Pure gold, platinum and palladium reportedly do not cause any adverse tissue reactions (Caputo, 1980). Evidence from tissue culture experiments would suggest that pure gold is inert (Sisca et al., 1967; Smith, 1982), and similar inertness has been shown for implanted gold in the dental pulp (Zander, 1959). Zetner, Plenk and Strassl (1980) however found a decrease in the number of cells in cultures exposed to particulate gold. High gold content alloys would also appear to be inert *in vivo* (Leirskar and Helgeland, 1972), with only a mild inflammatory reaction observed when implanted into rats (Mitchell, 1959; Nagem-Filho et al., 1975).

Local conditions such as the accumulation of plaque, or contact with a dissimilar metal may give rise to galvanic currents (Smith, 1982), and cause ionisation which may cause hypersensitivity reactions (Frykholm et al., 1969; Magnusson, Koch and Nyquist, 1970, 1971; Young, 1974; Fregert et al., 1979).

Copper has been known for years to produce adverse tissue reactions. Venable, Stuck and Beach (1937) noticed that copper was readily oxidised by body fluids and frequently caused aseptic suppuration. Zierold (cited by Venable et al., 1937) noticed that copper caused marked bone overgrowth and discolouration. McNamara and Williams (1982a,b) implanted copper and other metals subcutaneously in rats and studied the surface of the metal after implantation under the scanning electron microscope. They found much cellular debris and layers of protein around the implants. In studying the tissue by conventional optical microscopy, they demonstrated the presence of a thick striated

capsule and sterile pus (McNamara and Williams, 1981).

That silver causes an excessive inflammatory reaction *in vivo* was shown by Pudenz in 1942. Silver also exhibits moderate to severe corrosion when implanted into the body. Seltzer et al. (1972), in a study of silver cones recovered from endodontically treated teeth observed pitting, crater formation and globular and spherical accumulations on the metal surface. X-ray diffraction of the surface demonstrated the presence of sulphides, sulphates, carbonates, amino sulphates and amide hydrates. These corrosion products were found predominantly in areas which had been in contact with tissue fluid and saliva.

In a similar study, Palmer et al. (1979) demonstrated that endodontic silver cones placed protruding through root canals in monkeys caused root and bone resorption and repair with a moderate inflammatory response adjacent to the metallic point. Keller, Marshall and Kaminski (1984), in a comparison of silver, tin and copper implanted into peritoneal cavities of rats, found an intense inflammatory foreign body reaction to copper with an increased number of cells, whereas silver caused a decrease in adjacent cellularity, and no foreign body reaction. They attributed this to the cytotoxicity of silver.

Apart from these negative reports on the use of pure metals, precious and semi-precious metal alloys show more favourable responses, although most of the literature concerns their superficial use, such as in crown and bridgework, and partial denture construction.

A typical dental gold alloy contains 75% of gold and platinum combined (Phillips, 1982); lower gold content alloys have been developed with varying components;

usually silver is added at the expense of gold. To render the silver more tarnish resistant, and prevent precipitates of copper and silver, palladium is added in the ratio 1:3. Such silver-palladium alloys may contain only very small percentages of gold; Dentozyl®, one such alloy developed in Holland as a casting alloy for crowns and bridges, contains only 10% gold (NMT, 1986). Copper is added to strengthen gold alloys, and is permissible up to a content of 15% (Bosker, 1986) without affecting the alloy's resistance to corrosion. The Council on Dental Materials, Instruments and Equipment (1980) has laid down certain guidelines for low gold content alloys. A glance through any list of gold casting alloys reveals such a variation in content that any meaningful interpretation of any study on implanted gold alloys is difficult, if not impossible, except in comparison with other material groups.

Very little literature exists in the English language journals regarding implants of gold alloys. In a translation from the Dutch, Bosker and van Dijk (1983) stated that the alloy used in the transmandibular implant has been used in endodontic stabilisers in Europe for more than forty years, but no supporting references were given. Bosker (1986) studied the *in vitro* corrosion of the alloy used on the construction of the transmandibular implant in the presence of fluoride-containing toothpastes and found no corrosion after ten days. In a separate study, parts of an implant removed from a patient after two and a half years successful use were examined for corrosion by scanning electron microscopy and electron microprobe analysis. His results did not show any corrosion of the alloy.

Mjör and Hensten-Pettersen (1983) did state that there was little evidence of systemic toxicity using the non-precious metal alloys, but there is no doubt that

both types of alloys corrode with time. Brune, Evje and Melsom (1982) tested a gold alloy containing 75% gold, 14% silver and 6.6% copper for corrosion and found that silver and copper ions were released over a period of time *in vitro*. The same group of authors studied subcutaneous implants in rats by nuclear tracer techniques (Brune et al., 1983), and noticed that the metal implants were well received; but that during the acute inflammatory period immediately after insertion, the local tissue pH decreased, which they thought could lead to an increase in corrosion. Ion transfer took place, with the ions being deposited in adjacent tissues at a minute rate.

Silver-palladium alloys demonstrate lower chloride resistance than gold alloys (Sarkar, Fuys and Stanford, 1979a,b). Attack of the silver-rich phase, perhaps leading to tarnish in the oral environment, may indicate that ion release is possible over a period of time. No long term reports have been published, but biological implications seem unlikely. No reports have been found regarding implantation of these low gold content alloys in bone.

2.5 POLYMERS

Although polymers are widely used in orthopaedic implant surgery (Williams, 1981a), their relatively poor mechanical properties make them unsuitable for most load-bearing applications. Their use is well established in the cranial and facial implant field (von Fraunhofer, 1975). The only polymers which have been used to any extent in dental implants are polymethylmethacrylate and Proplast®, a composite of polytetrafluoroethylene and carbon fibres, which has been described for use in alveolar ridge augmentation (Kent et al., 1972).

a) Acrylics

Polymethylmethacrylate has been used in the tooth root implant system (Hodosh et al., 1969, 1970; Taylor and Smith, 1970). Anatomical tooth root replica implants with a degree of surface porosity were found to become self-supporting and acted as satisfactory supports for prostheses in humans (Hodosh et al., 1973), with a pseudo-periodontal ligament containing connective tissue fibres running perpendicular to the implant's surface. Despite these early promising results, the use of acrylic tooth replacements has now largely been discontinued, due to the inherent disadvantages of the polymers. Additives and free monomer are present within a polymer, and may be leached from it, causing fibrosis, osteomyelitis and on occasions more serious systemic conditions (Oppenheimer et al., 1956; Hamner, Reed and Hand, 1970). Embrittlement of the polymer may also occur. The physical form of polymers has an influence of the tissue reactions; particulate material inducing a more intense inflammatory reaction (Oppenheimer et al., 1956).

Worley (1973) described the histology of the interface of acrylic with bone and mucosa six weeks after implantation into dogs. The mucosa was mainly normal, with some areas of chronic inflammation. Connective tissue separated the implant from the bone, with the presence of some foreign body giant cells being noted.

2.6 CERAMICS

Ceramics are substances made from non-metallic minerals, usually by firing at high temperatures. The specific gravity, coefficient of friction, strength and surface qualities of ceramics are similar to those of bone (Bhaskar et al., 1971). They are non-toxic, non-

inflammatory and non-antigenic (Weinberg and Moncarz, 1974). They possess little flexural strength and no ductility. Their fabrication into complex shapes is difficult. Hench (1981) classified implantable ceramics into three categories;

1) the nearly inert, e.g. aluminium oxide. These show no specific adhesion to tissue.
2) the absorbable, e.g. tricalcium phosphates.
3) ceramics with controlled surface activity, e.g. bioactive glasses and glass ceramics. These display adhesion to tissues.

a) Alumina

Aluminium oxide (Al_2O_3) is produced by sintering, producing surface porosities, which are of value in gaining stability and tissue ingrowth into an implant. It is extremely stable in a physiological environment and its abrasion resistance is of value in articulating surfaces.

Attempts have been made to fabricate endosseous dental implants from alumina. When implants with a pore size of 100-750 μ were placed in mandibles of monkeys, all demonstrated fibrous tissue and bone ingrowth into the interconnecting channels (Pedersen, Haanaes and Lyng, 1974; Furseth and Pedersen, 1978). Topazian (1971), in experiments conducted in dogs, noted fibrous tissue ingrowth, and also an absence of inflammatory cells and foreign body giant cells when they investigated alumina endosseous dental implants. When attempts were made to load such implants, a fibrous capsule developed around the implant, due to the inevitable relative movement resulting from the large difference in the modulus of elasticity between the bone and alumina (Heimke et al., 1979). Bacterial invasion through the porosities has

been reported to occur (Klawitter et al., 1977) if these extend into the intra-oral part of the implant. Aluminium oxide implants are no longer in general use.

b) Tricalcium phosphates

A wide range of calcium phosphate salts has been investigated for implant use (Williams, 1981a), with calcium to phosphate ratios ranging from 0.5 in hydrated calcium phosphate to 2.0 in tetracalcium phosphate. All are similar in crystal structure to calcium hydroxyapatite ($Ca_{10}[PO_4]_6[OH]_2$), and show similar behaviour on implantation, with bone in apposition with the implant. The nature of the material would appear to determine whether or not it is degraded in the body.

Plaster of Paris is a simple inexpensive ceramic, being stable, readily available and easily sterilised (Topazian et al., 1971). It is well tolerated by hard and soft tissues (Bell, 1964), and does not appear to stimulate either chronic inflammatory reactions or foreign body giant cell activity (Peltier, 1961). It has been used in the experimental repair of periodontal defects (Alderman, 1969).

If the material is porous, degradation by cellular activity occurs and bone completely replaces the implant. Levin et al., (1974) implanted tricalcium phosphate in dogs and noticed that the ceramic was continuously removed from the site by small multinucleated giant cells, until removal was complete after twenty-two weeks. Vessels grew into the porous structure and were eventually surrounded by osteoid with osteoblastic activity, initially at the edge of the ceramic, and then within the islands of the connective tissue. Mors and Kaminski (1975) were in agreement with these findings. The use of this type of porous ceramic for

alveolar ridge augmentation has been reviewed by Griffiths (1985), in periodontal defects (for example Levin et al., 1974), and also as a coating on tooth root implants, with promising results (Kent et al., 1986; Jarcho et al., 1986; Cook et al., 1986).

Dense calcium hydroxyapatite has been used as a tooth root implant by Denissen and de Groot (1979), with promising initial results. The dense material was rendered stable by impregnation with polyhydroxyethyl-methacrylate and then sintered to give a material of very low porosity. Animal experimentation showed that the bone adapted closely to the implants, with bone bridges forming over them. This type of implant would seem a promising development in the prevention of atrophic ridges, rather than in the treament of them.

c) Bioactive glasses and glass ceramics

In these materials, bonding to bone is achieved through an ion exchange process (Osborn and Newesely, 1980). The ratio of glassy matrix and alkali ions determines the ion exchange capacity. At the interface of the implant, a silica-rich layer is formed by dissolution and ion exchange processes. A surface film of calcium phosphate, derived mainly from the interstitial fluid and ions of the adjacent bone tissue, is deposited on the silica-rich layer. Most potential applications for this relatively new material lie in the orthopaedic field, and early experiments using "bioglass" as tooth replacement implants in baboons were not successful (Stanley et al., 1976).

2.6 CARBON

Carbon is available in a wide variety of forms, from soft amorphous graphite to the extremely hard diamond, and is inert. The two forms of carbon of interest in the field of implantology are pyrolitic graphite and vitreous (or glassy) carbon.

a) Pyrolitic graphite

Pyrolitic graphites are prepared by thermal decomposition of hydrocarbon gases, with temperature and composition of the fluidising gases being responsible for the resultant properties. Although this material has been used in endosseous implants (Williams, 1981a), its use is not widespread.

b) Vitreous carbon

Vitreous carbon is prepared by the thermal degradation of organic polymers under an inert atmosphere and then under vacuum. It is hard and strong, with a low density and negligible porosity. Its modulus of elasticity is similar to that of cortical bone (Hucke, Fuys and Craig, 1973). Tooth root implant systems have been made by machining vitreous carbon; for example, the Vitredent™ system (Vitredent Corporation) is available in a range of sizes simulating normal tooth root morphology (Schnitman and Shulman, 1980). These can be placed in fresh extraction sockets or in sockets prepared in edentulous ridges. In 1979, Al-Salman, Sayegh and Chappel demonstrated the presence of a thick connective tissue layer along the interface one month after these implants were placed in dogs. Within the crypts of the implant a vascular highly cellular connective tissue was seen to contain fibroblasts. After three months, a direct bone to carbon relationship had developed.

However, clinical trials did not prove to be as successful, and the Harvard Conference in 1978 recommended that the system be limited to clinical trails (Natiella, 1980b). Schnitman and Shulman (1980), reporting on further clinical trials concluded that the vitreous carbon tooth root could no longer be recommended as a free-standing implant.

CHAPTER 3 MATERIALS AND METHODS

3.1 ANIMALS

In this investigation, twelve pure bred Merino wethers were used, selected at random from common stock specifically bred for experimental research in agriculture at the Waite Agricultural Research Institute, University of Adelaide. The sheep were all mature animals, over three years of age, and had all their teeth fully erupted. All sheep were in good condition, were free from disease, and weighed approximately 70kg.

Sheep were selected as the experimental animal in this investigation because of their relatively large size, permitting the insertion of an adequate size of implant, and the relative ease of availability in numbers and cost. The experiment had the approval of the Animal Ethics Committee of the University of Adelaide.

The animals were provided by, operated on, fed, maintained and sacrificed at the Waite Agricultural Research Institute, University of Adelaide. Prior to being selected for the study, the animals were kept in open fields, with unrestricted access to adequate natural food and water supplies. After being accepted for the study on the criteria cited above, the sheep were transferred to individual holding pens in a covered shed with natural daylight. The pens are specifically designed to hold sheep over many months, and have dimensions of 1.30m by 0.90m. The sheep had free access to water, and were fed twice daily with a combination of lucerne processed in a chaff cutter, and sheep pellets (Milling Industries Ltd., Adelaide). The concrete floor underneath the pens was hosed down daily.

3.2 SOURCES OF METALS

Seven metals were chosen for investigation in this study; platinum, palladium, silver, copper, gold, Dentozyl® and the gold alloy used for the Bosker transmandibular implant (Bosker and van Dijk, 1983). The pure metals used comprised the chief constituent metals of the two alloys.

The chemical composition of the gold alloy is stated by the manufacturers to be:

gold	70.0%
platinum	5.0%
silver	12.8%
copper	12.2%

That of Dentozyl® is stated to be:

silver	54.5%
palladium	22.0%
gold	10.0%
platinum	10.0%
copper	2.0%
zinc	1.0%
ruthenium	0.5%

(Bosker, 1985).

The metals were cast into rods of 2mm diameter, and the surface blasted to give a pore size of between 1.68μ, and 2.18μ, identical to that of the transmandibular implant (Bosker and van Dijk, 1983). The metals were then cut into lengths of approximately 2cm. All metals used were supplied by H. Drijfhout & Zoon's Edelmetaalbedrijven B.V., Amsterdam.

Prior to implantation, the rods were cut into the individual lengths on a metal working lathe, in a specially constructed jig, to ensure a standard length

of 15mm, and the ends finished in an identical fashion (University of Adelaide Engineering Workshop). The implants were then sealed in individual bags and sterilized by steam at 121°C for 15 minutes in the Central Sterile Supply Department of the Adelaide Dental Hospital. Implants were subsequently stored until used.

3.3 PRELIMINARY EXPERIMENT

To determine the order of placement of the seven metals in the mandible, a preliminary experiment was developed and performed with advice given by Dr. Barry Steel of the Department of Physical and Inorganic Chemistry, University of Adelaide. The aim was to measure the electrical potential of each metal with respect to both a standard Calomel electrode and each other in a laboratory situation. The test conditions were evolved to create as similar a situation as possible to that which would exist *in vivo*..

A tibia was obtained from a newly killed sheep, and all soft tissue except the periosteum was removed. Seven holes of 2mm diameter were prepared at 15mm intervals along the bone, using an orthopaedic hand drill fitted with a stainless steel drill bit, and 0.9% saline as an irrigant/coolant. A further hole of 5mm diameter was prepared to the same depth to accommodate the Calomel electrode.

One of each of the seven metals to be used in the major study was then tapped into place in a random order using a surgical mallet. The standard Calomel electrode was placed in the larger hole. The bone was then immersed in a bath of Ringer's solution at 37°C, and one lead of a high impedance voltmeter connected to the Calomel electrode (Fig. 3.1). The other lead was placed on each

electrode in turn and the potential read and recorded after ten seconds. A total of three readings were taken for each metal.

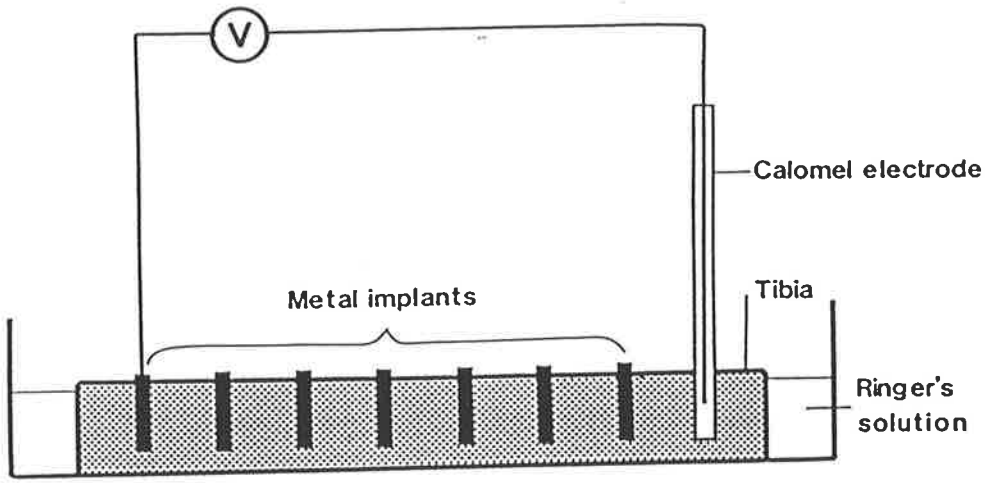


Fig. 3.1 Diagram showing the design of the preliminary experiment.

The experiment was repeated using each of the seven metals in turn as the reference. Three readings were taken for each metal. The average value of each series of readings was calculated and is presented in Appendix II. From Appendix II, the order of potential with respect to the Calomel electrode was determined to be:

platinum
palladium
gold alloy
gold
silver
Dentozyl®
copper

3.4 ANAESTHESIA AND SURGERY

a) Anaesthesia

Prior to surgery, each sheep was shorn to make surface anatomy more visible. Each sheep was fasted for forty-eight hours, to ensure an empty stomach during the period of anaesthesia. They were then transferred to pens in an air-conditioned room, adjacent to the operating theatre, with artificial daylight. Immediately post-operatively, they were transferred back from the theatre to these pens, where they were kept under observation until recovered.

At the time of operation, a technical assistant steadied the sheep whilst the surgeon performed venepuncture of either the left or right external jugular vein, after skin preparation with an aqueous solution of cetrimide and chlorhexidine (Savlon®, ICI Australia Operations Pty. Ltd.). Sodium pentobarbitone (Nembutal®, Abbott Laboratories Pty. Ltd.) was then injected, aspirating at intervals to check the patency of the venepuncture. Sodium pentobarbitone is a derivative of barbituric acid, and acts as a depressor of the central nervous system. As such, it is regarded as one of the anaesthetics of choice for veterinary procedures in larger animals such as the sheep. An initial dose of 20ml (60mg/ml) was given, then increments of 1-2ml given until the animal began to drop, and the eyelash reflex disappeared. The average dose for induction was 25ml (range 17-29ml). The needle was then removed and pressure applied to prevent haematoma formation.

The sheep was then transferred to the operating table using a harness and hydraulic lifter. It was positioned on its side, with shoulders slightly elevated and the head inferiorly, to prevent inhalation of saliva and vomit. The medial aspect of the lower-most hind limb was then shaved, and a peripheral vein cannulated with a 21G

Jelco™ catheter (Critikon Inc., USA.) after routine skin preparation. This was secured in place with surgical tape and connected to an infusion of sodium pentobarbitone, which could then be administered in 2ml increments when necessary.

Post-operatively, the cannula was removed and manual pressure maintained on the vein for several minutes. A pressure dressing was applied and the sheep removed from the table. It was placed on its side in the coma position with legs curled under, the shoulders raised and the head extended.

b) Surgical Procedure

Once the sheep was positioned on the table, the head was tilted to one side and the neck extended. If necessary, surplus wool was clipped from the submandibular region. A tray of sterile instruments was opened (Appendix III), and the surgeon donned a clean gown and sterile gloves. The skin at the surgical site was prepared with aqueous cetrimide and chlorhexidine (Savlon®) (Fig. 3.2).

A linear incision was made through skin and subcutaneous tissue approximately 1.5cm inferior to the lower border of the mandible, and immediately anterior to the angle. Blunt and sharp dissection through to the lower border of the mandible was performed, taking care to preserve the facial nerve. The facial vein was ligated and cut if encountered during surgery. The periosteum of the lower border was then exposed as near as possible to the angle, extending forward for a minimum of 6cm (Fig. 3.3).

Using retractors to protect the soft tissue to the lingual of the mandible, the periosteum was incised and raised at the lower border (Fig. 3.4). Using an

orthopaedic hand drill fitted with a stainless steel drill and 0.9% saline as irrigation/coolant, a hole of 2mm diameter and 15mm depth was then made in the bone. The drill was directed as near as possible to perpendicular to the lower border, and in the centre of it (Fig. 3.5). The hole was copiously irrigated with saline to remove any debris and further holes drilled at 15mm intervals along the lower border (Fig. 3.6). Subsequently a metal implant was gently tapped into each hole with a surgical mallet (Fig. 3.7) in the pre-determined position (Section 3.3), noting and recording the ease of implantation and the position of the top of the implant in relation to the bone surface. In this way, four implants were placed in the right side of the mandible and three in the left side (Fig. 3.8).

The incisions were then closed in layers, using 2/0 resorbable polyglycolic acid sutures (Vicryl™, Ethicon Inc., USA) in the deep layers, and 3/0 black silk in the skin (Figs. 3.9 and 3.10). The sutured incision line was cleaned and dusted with an antibiotic powder containing bacitracin and neomycin (Cicatrin®, Wellcome Australia Ltd.).

The sheep was then turned over and the procedure repeated on the other side.

Intra-operatively, all animals received an intra-muscular injection of 10ml of procaine penicillin, 300g/ml (Vetspen®, Glaxo Australia Pty. Ltd.), and radiographs made of the implant immediately post-insertion.

c) Post-operative management

Post-operatively, the sheep were transferred to the pens in the Anaesthetic Room for the remainder of the day.

They were recovered in the Coma position and observed at intervals until standing in alert fashion. Urine output was noted and the sheep then returned to the large holding shed, where food and water was available.

Initially the wound sites were checked daily by the surgeon, then weekly for signs of infection. The sheep were fed their daily rations of dry feed by the farm-hand, and had water *ad libitum*. Any reluctance or inability to eat was noted and the sheep's general condition monitored. They remained in the holding pens until the time of sacrifice.

3.5 SACRIFICE

Times of sacrifice were determined at four and thirteen weeks in accordance with the F.D.I. criteria on implant research (Langeland and Cotton, 1979). At the allocated time interval, the sheep were sacrificed by exsanguination.

The skin of the head was immediately removed, and the mandible disarticulated from the cranium. The mandible was further split at the symphysis, labelled for future identification, and placed in 10% neutral buffered formalin solution (Appendix IV).

3.6 PREPARATION FOR HISTOLOGICAL INVESTIGATION

a) Radiography and removal of soft tissue

As soon as practically possible after sacrifice, each hemi-mandible was radiographed. A lateral film was made with the mandible resting on the film cassette with the buccal aspect uppermost. A Lanex fine screen was used in conjunction with Kodak Ortho-G film. The target to film

distance was 100cm and the exposure time 0.1 second at 52kV and 100mA.

The soft tissue overlying the surgical site was then examined and removed in the same sequence as the initial surgery, and the periosteum stripped off.

The appearance of the implants and surrounding bone was noted and recorded, and further radiographs made. Kodak Ultra-speed occlusal film was used with a target to film distance of 25cm. The mandible was again placed with the buccal aspect uppermost on the film. Exposure was 0.4 seconds at 50kV and 10mA.

Smaller periapical radiographs were made of some metals using the same exposure factors with rectangular beam collimation.

b) Sectioning the mandible

After allowing a minimum of three days for adequate infiltration of the fixative, the mandible was sectioned into pieces each containing one implant.

The position of the implants was calculated by super-imposing a tracing of the lateral radiograph on the bone and marking the latter. Using a diamond saw with water coolant, the bone was cut with a margin of at least 5mm all round the implant. No attempt was made to reduce the bone in a bucco-lingual direction.

c) Histological investigation

Of the six sheep in each time period, tissue from three was studied as undecalcified material, and tissue from two as decalcified material. Tissue from one animal was retained as reserve specimens.

(i) Decalcified sections

After sectioning the bone into individual pieces each containing one implant, the bone blocks were decalcified in a commercially obtainable decalcifying agent containing hydrochloric acid and a chelating agent (Decal II®, Surgipath Medical Industries Inc., USA.). The specimens were radiographed at daily intervals until decalcification was complete.

At the end point of decalcification, the metal implants were gently removed from the tissue with tweezers. In those cases where the cortical end of the metal implant had been completely covered by bone, a small incision was made over the end of the implant, in order to effect recovery. Each metal implant was subsequently placed in absolute alcohol, prior to further investigation by scanning electron microscopy.

The decalcified bone was trimmed buccally and lingually with a scalpel using minimal pressure and double embedded in paraffin wax under vacuum (Appendix V). Specimens were orientated to obtain longitudinal sections of the implant space.

Histological sections of 7μ thickness were obtained on a Leitz rotary microtome, and collected from three areas across the implant space. One set of serial sections was stained with haematoxylin and eosin (Appendix VII), and another with trichrome (Appendix VII). The sections were then examined using an Olympus CH light microscope and assessed with respect to the following parameters:-

1) presence or absence of inflammation, and distribution if present.

2) presence, absence, and character of fibrous tissue around the implant.

3) the relationship of the bone to metal implant.

All three parameters were assessed separately for cortical and cancellous bone, and recorded on the proforma shown in Appendix VI.

(ii) Undecalcified sections

The bone was dehydrated through a series of alcohols, defatted in xylene, rinsed in alcohol to remove the xylene, placed in acetone before being infiltrated with an acetone/resin mixture. It was finally embedded in fresh resin and polymerised for forty-eight hours at 60°C (Appendix VIII).

Prior to sectioning, each block was orientated so that the plane of section would pass through the long axis of the implant, and parallel with the buccal cortex.

50µ sections were then cut using a Leitz 1600 saw microtome in the following manner; the base of the specimen was attached to the holder with Araldite® glue (Ciba Geigy Australia Pty. Ltd.) and mounted in the microtome. A standard glass microscope slide was glued to the upper surface with cyanoacrylate cement (Supa-Glue®, Selleys Chemical Co. Pty. Ltd.) and the micrometer guage set to cut specimens of 50µ thickness. Automatic advancement through the rotating diamond impregnated blade with water coolant resulted in the sections being obtained.

Sections were examined using a Wild Photomakroscop, Model M400, using the same parameters as for the decalcified sections. The specimens were examined prior to staining, and after staining with a modified trichrome stain (Appendix VII).

(d) Scanning electron microscopy of the metals

After being removed from the decalcified blocks, the implant metals were stored in absolute alcohol, then air dried prior to being mounted on standard aluminium stubs using silver adhesive (Electrodag 915™, Acheson Colloids Co., UK). The metals were then surface coated with 15nm of carbon followed by 20nm of 80% gold/20% palladium alloy in a Denton Vacuum Model 502 high vacuum evaporator fitted with a rotating tilting specimen stage (University of Adelaide Electron Optical Centre) and then examined in the Seimens ETEC Autoscan scanning electron microscope operated at a beam voltage of 20kV.

Each implant was examined for degree and type, if any, of surface corrosion, presence of organic surface film, and adherent organic or inorganic matter. Control metals which had not been stored in any fixative were examined in a similar fashion, as were control metals that had been subjected to the same preparation through fixatives and decalcifying agents as the mandibles destined for study as decalcified sections.

(e) Electron Microprobe Analysis

One set of implant metals from each time period was subjected to qualitative electron microanalysis for identification of the surface elements.

After air drying, the metals were mounted on a standard glass microscope slide using double-sided adhesive tape, and carbon conducting medium applied to each end of the specimens and coated with 15mm of carbon (to avoid interference from the coating). Analysis of the samples was performed using a Tracor Northern TN 5500 model EDS system on a Philips scanning electron microscope using an accelerating voltage of 20kV and an electron beam current of 3nA.

(f) Quantitative microanalysis

Quantitative analysis of control specimens of the gold alloy and Dentozyl® was performed using a JEOL 733 Superprobe model scanning electron microprobe analyser equipped with three EDS crystal spectrometers and a KEVEX 5000 series EDS system with a take-off angle of 40° and a counting time of 60 seconds (University of Adelaide Electron Optical Centre).

The metals were embedded in Araldite-D® resin (Ciba Geigy Australia Pty. Ltd.) and surface polished to lu prior to examination (University of Adelaide Geology Department).

Fig. 3.2 Photograph showing sheep's head extended prior to commencement of surgery. The dotted line (.....) indicates the incision line.

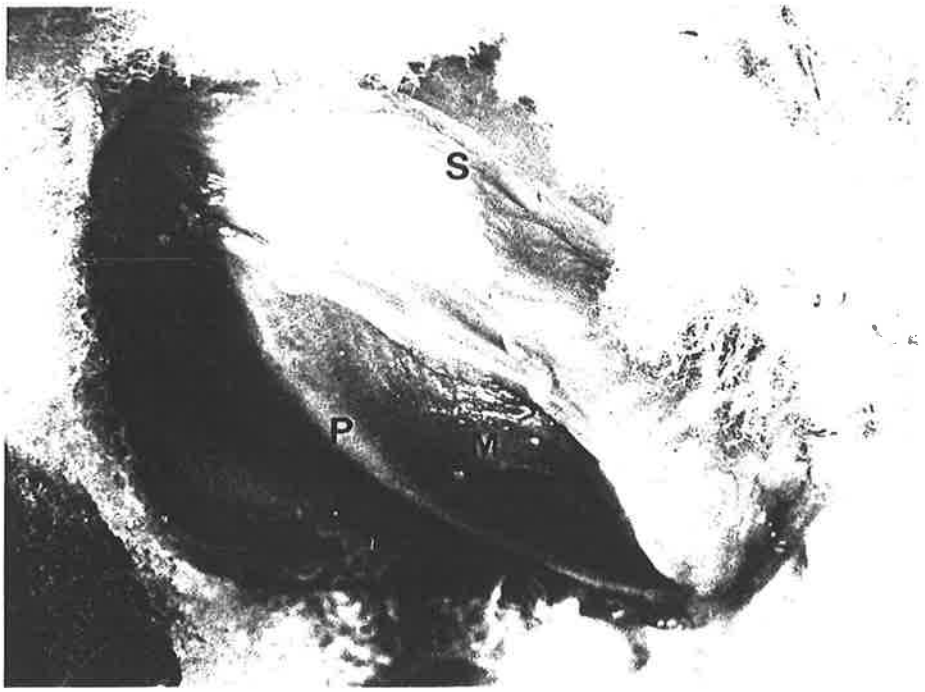


Fig. 3.3 Photograph showing incision through skin and subcutaneous tissue (S), exposing the muscle (M) and periosteum (P) of the lower border of the mandible.

Fig. 3.4 Photograph showing the periosteum incised over the lower border of the mandible, with reflection of a small amount of muscle (M). The retractor (R) is positioned to protect the lingual soft tissues.

Fig. 3.5 Photograph showing the position of the drill for preparation of the first hole in the mandible.

Fig. 3.6 Photograph showing four holes prepared along the lower border of the mandible on the right side.

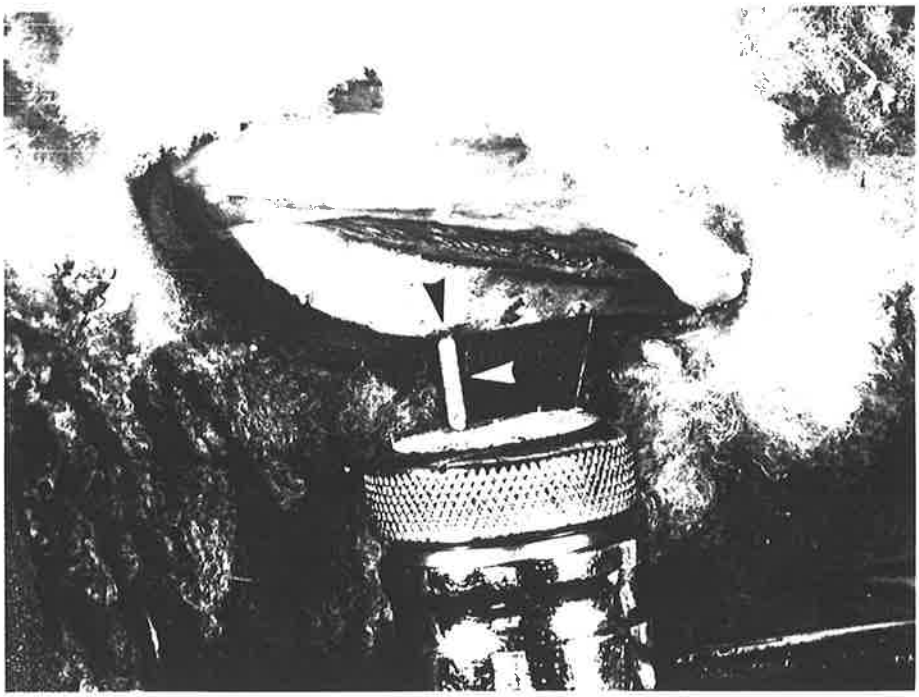


Fig. 3.7 Photograph showing a metal implant (arrowed) being tapped gently into place with the surgical mallet.

Fig. 3.8 Photograph showing three of the four metals in place along the lower border of the mandible on the right side. The fourth implant is covered by soft tissue.

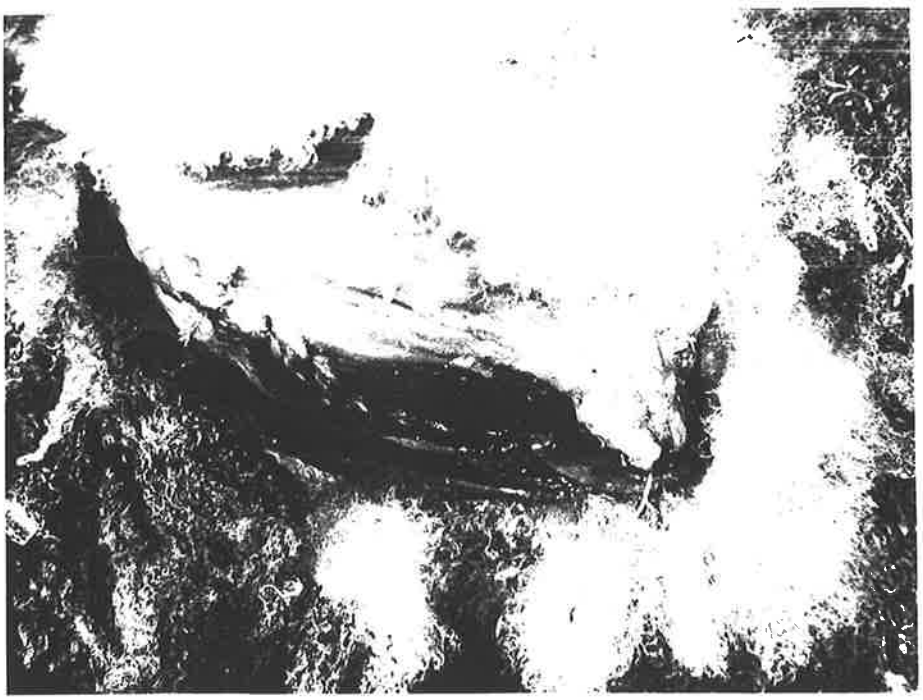


Fig. 3.9 Photograph showing closure of the periosteum and deep soft tissue layers with a continuous resorbable suture (Vicryl™).

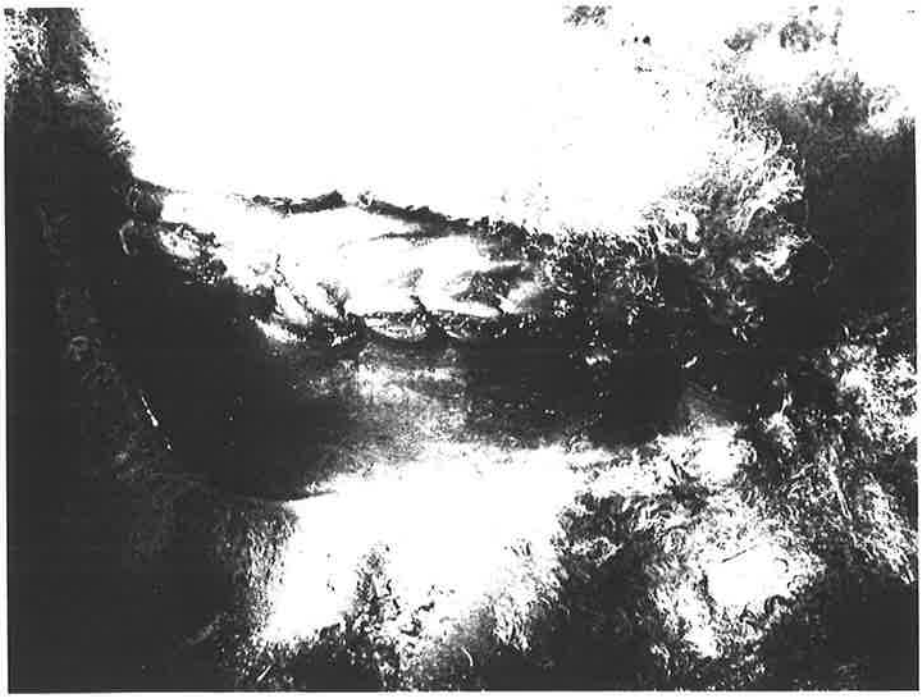


Fig. 3.10 Photograph showing closure of the subcutaneous tissues using a continuous suture (Vicryl™), prior to closure of the skin with interrupted black silk sutures.

CHAPTER 4 RESULTS

4.1 GROSS OBSERVATIONS

a) MORBIDITY

One animal suffered a cardiac arrest intra-operatively; it was resuscitated using external cardiac compression and recovered normally. No other animal suffered any complications and all survived until the designated times of sacrifice. During the post-operative period, no animal appeared to be in any discomfort; and all sheep ate and drank normally with no obvious functional problems.

b) AFTER FOUR WEEKS

In all sheep the skin was intact and the incision along the lower border of the mandible was well healed. The silk sutures were still in place in the skin. Upon removal of the skin, the resorbable sutures were seen, together with some haematoma of the tissues.

Copper

Macroscopic examination of the tissues around each implant revealed an area of tissue necrosis and bone destruction. Thick pus was present around each implant for a distance varying from 2mm to 10mm (Fig. 4.1); this was adherent to the periosteum. Each implant was loose and discoloured.

Dentozyl®

No tissue reaction was visible within bone or periosteum upon macroscopic examination of the area around the Dentozyl® implants; the periosteum stripped cleanly away from bone. There was no macroscopic evidence of corrosion of the metal implants. One implant was noticed to have split longitudinally (Fig. 4.2) .

Silver

No tissue reaction in bone or periosteum was visible at a macroscopic level; the periosteum stripped cleanly away from bone. The implants had discoloured to a golden colour.

Platinum

In one sheep the implant protruded through the lingual cortex. This had been expected since the time of surgery when it was noted that the drill had met an area of little resistance. The implant was enveloped in soft tissue and was not mobile.

In two sheep the implants were not visible at the lower border of the mandible, and appeared to be covered by a layer of new bone. These implants had been flush with the lower border of the mandible at the time of surgery.

In the remaining four mandibles the bone showed a brown discolouration immediately adjacent to the implant for about 1mm; an appearance consistent with haematoma (Fig. 4.3). The implants did not appear to be clinically corroded.

Palladium

There was no obvious tissue reaction in bone or periosteum around three implants which were standing proud of the lower border of the mandible. The metal did not appear corroded.

The remaining implants had been placed flush with the inferior cortical border of the mandible at the time of surgery were no longer visible; and appeared to be covered by a layer of new bone (Fig. 4.3).

Gold alloy

Two implants were still visible at the lower border of the mandible; no tissue reaction or corrosion of the metal could be seen around these implants.

Four implants had been flush with the bone initially;

these were no longer visible and appeared to be covered by a layer of new bone or fibrous tissue (Fig. 4.3). A cuff of tissue could be seen around the neck of one implant, which has been standing proud of the lower border of the mandible since placement.

Gold

No tissue reaction in bone or periosteum or corrosion of the metal was apparent around any of the gold implants.

c) AFTER THIRTEEN WEEKS

In all sheep the skin was intact and the skin incision along the lower border of the mandible well healed. In five cases the silk sutures in the skin were no longer present; the sutures were still in situ in the remaining sheep.

Upon removal of the skin, the muscle layers appeared well healed and intact. The polyglycolic acid sutures were no longer present. The periosteum had healed well.

Copper

In all mandibles adjacent to the copper implants there was gross bone destruction and fibrous tissue formation, the latter being adherent to the periosteum. In one case the implant had been extruded from the bone into this fibrous tissue, the edge of the implant being approximately 12mm from the original lower border of the mandible.

The cortical bone around the copper implants demonstrated a proliferative reaction and bulging of the inferior border.

The tissue around all six implants showed an extracapsular necrotic area of cottage cheese consistency (Figs. 4.4 and 4.5), not dissimilar from caseation

necrosis. The implants were clinically corroded and black in colour.

Dentozyl®

There was no tissue reaction visible in bone or periosteum upon macroscopic examination of the mandibles around the Dentozyl® implants. The periosteum stripped away cleanly from around each implant, which did not appear tarnished or corroded (Fig. 4.5).

Silver

There was a slight brownish discolouration of the bone and periosteum extending for approximately 1mm from the implant, and destruction of the edge of the cortical bone around the implants. All implants exhibited a golden discolouration (Fig. 4.5).

Platinum

No tissue reaction in bone or periosteum was apparent upon macroscopic examination of the tissue around two platinum implants. The metal did not appear corroded.
In the remaining four sheep the implants were not visible; the area was seen to consist of hard tissue, the nature of which appeared identical to the surrounding unoperated bone.

Palladium

No tissue reaction in bone or periosteum was apparent upon macroscopic examination of the tissue around two of the palladium implants. The metal did not appear corroded.
In the remaining four mandibles, the implants were not visible; the area was noticed to consist of hard tissue; the nature of which appeared identical to areas where no implants had been placed (Fig. 4.6).

Gold alloy

No tissue reaction in bone or periosteum was visible upon macroscopic examination of the tissue around two of the gold alloy implants. The metal did not appear corroded. There was a cuff of hard tissue around the neck of one of these implants, which had been standing proud of the lower border of the mandible since implantation.

In the remaining four sheep the implants were not visible; the area was noticed to consist of hard tissue, the nature of which appeared identical to areas of adjacent unoperated bone (Fig. 4.6).

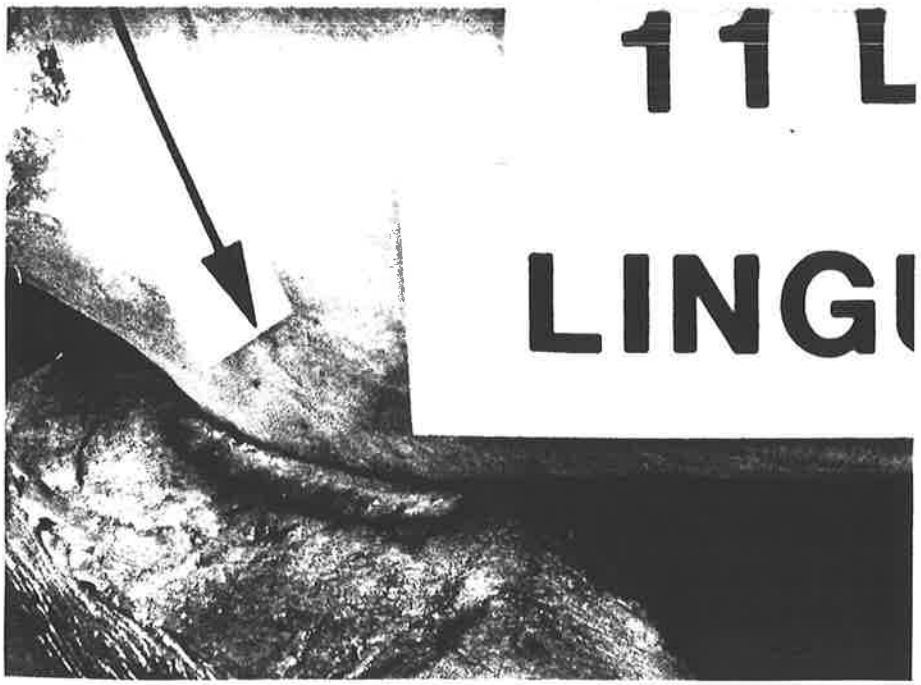
Gold

No tissue reaction in bone or periosteum was apparent upon macroscopic examination of the tissue around the gold implants. The metal did not appear corroded. One metal implant appeared to be distorted at its inferior end (Fig. 4.6 inset).

In the remaining four sheep the implants were not visible; the area was seen to consist of hard tissue, the nature of which was similar to adjacent normal bone (Fig. 4.6).

Fig. 4.1 Photograph of the tissue reactions observed around a copper implant after four weeks implantation. Pus can be seen around the implant (arrowed).

Fig. 4.2 Photograph showing a recovered Dentozyl® implant which is seen to have split longitudinally.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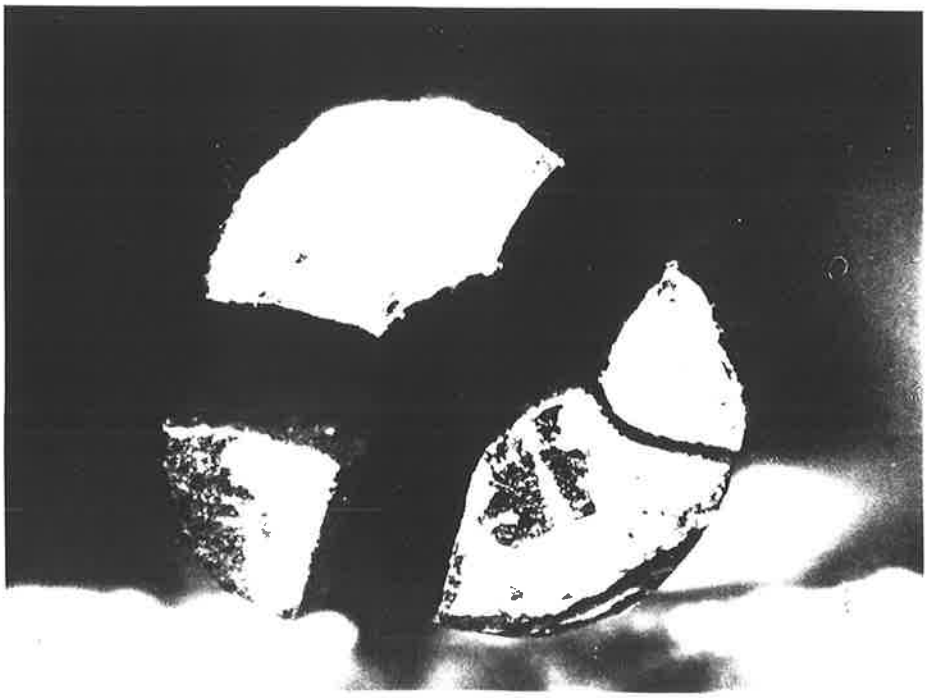
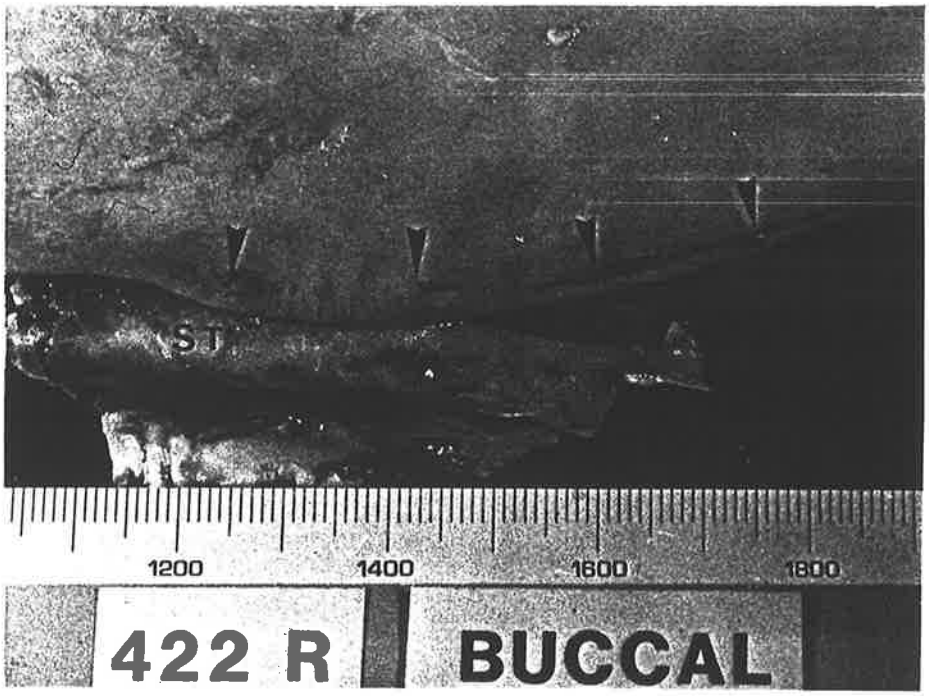


Fig. 4.3 Photograph of the inferior border of the right side of a mandible and the reflected periosteum and soft tissue (ST). A brown discolouration of both bone and periosteum is apparent; this is consistent with haematoma formation. All the implants appear covered with new tissue; their sites, confirmed by radiography are marked with arrows.

Fig. 4.4 Photograph showing the gross appearance of the soft tissue overlying a copper implant after thirteen weeks implantation. An area of necrosis has been incised and reflected. The necrotic tissue appears well-defined from the surrounding soft tissues.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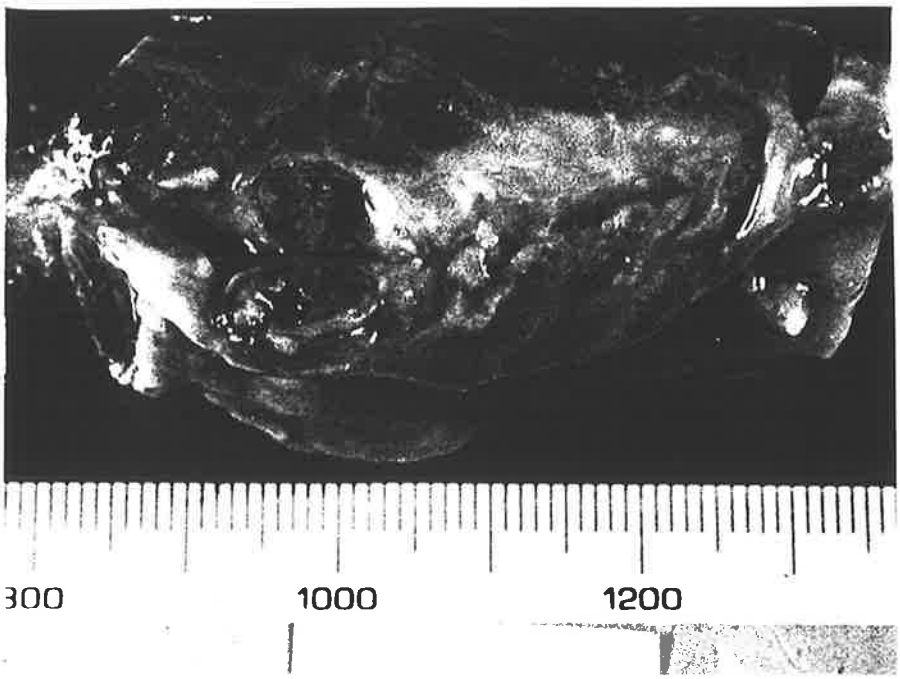
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Fig. 4.5 Photograph showing the buccal aspect of the left side of a mandible from a sheep in the second experimental group. The arrow points to an area of necrotic tissue around the copper implant. A slight brownish discolouration of the bone is seen around the silver implant (on the left), which itself appears a slightly golden colour. No obvious tissue reaction can be seen around the Dentozyl® implant (centre).

Fig. 4.6 Photograph showing the buccal aspect of the right side of the mandible after thirteen weeks implantation. In this specimen, only the gold alloy implant is visible (arrowed). The remaining implants (platinum, palladium and gold) have been covered with new tissue.

INSET: photograph of the inferior aspect of a gold implant, showing distortion in the form of lipping of the surface.


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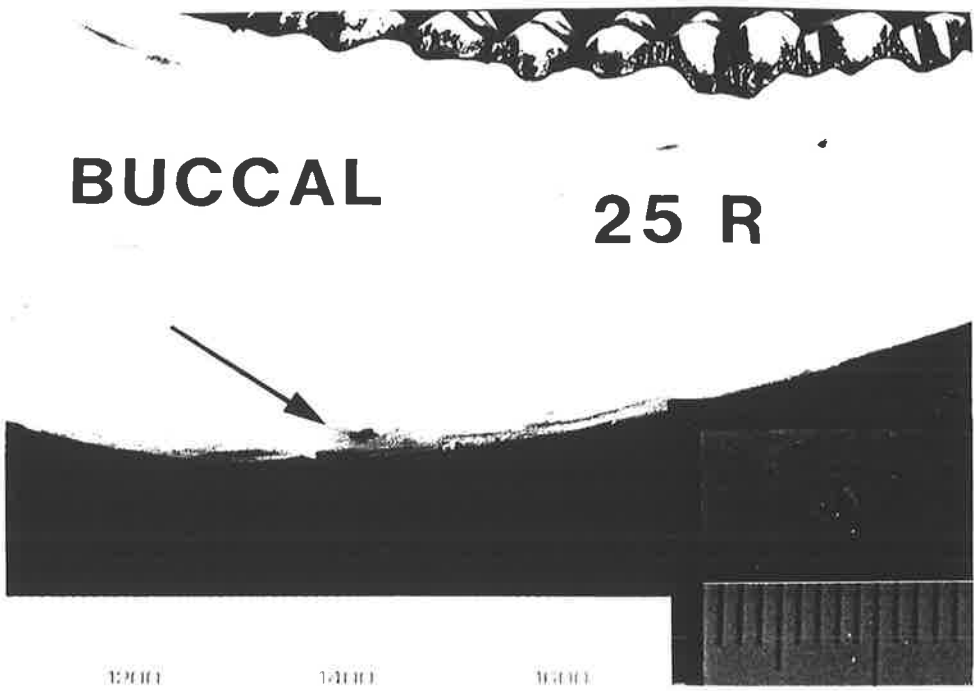
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4.2 RADIOGRAPHIC RESULTS

Examination of the radiographs taken at the time of sacrifice showed that the metals were implanted in different relationships to the mandibular teeth, cortical and cancellous bone and inferior dental canal. The varying position of each metal at the end of both experimental time periods is shown diagrammatically in Figures 4.7 and 4.8.

Imaging of the thickness of cortical bone varied from approximately 2mm in the body of the mandible to a barely detectable thickness at the angle. The radiodensity of cancellous bone was seen to vary from area to area, both in experimental and control mandibles.

a) AFTER FOUR WEEKS

Copper

An implant appeared in direct relationship with the teeth in two of the six mandibles. Increased radiolucency of bone adjacent to all copper implants was observed, entirely surrounding the implant. The radiolucencies had ill-defined and irregular borders.
Changes noticed within the cortical plate could be divided into three groups:

i) inferior bulging of the cortex without thickening (Fig. 4.9a).
ii) thinning of the cortex in one mandible (Fig. 4.9b).
iii) inferior bulging of the cortex with thickening (Fig. 4.9c).

Dentozyl®

Three of the six implants appeared in close relationship with the teeth.

Radiographs of five mandibles did not show any evidence of bony tissue changes adjacent to the Dentozyl® implants (Fig. 4.10b).
In one specimen features of bone deposition could be seen. There appeared to be a reaction within the cortical plate resulting in an increase in thickness of cortical bone towards the medullary cavity (Fig. 4.10a).

Silver
One of the implants appeared to be in direct relationship with adjacent teeth and another two appeared slightly bent along their entire length (Fig. 4.11a).
Within the cancellous bone there was some evidence of increased radiolucency within the cortical bone around five implants (Fig. 4.11b).
One case showed evidence of periostitis with new bone formation (Fig. 4.11c).

Platinum
One of the six implants was imaged in direct relationship with the teeth. Three of the six radiographs showed the implants to be situated in a region where there was little or no thickness of the cortical bone.
In all cases there were no features illustrating alteration in bone density, and the radiodensity and thickness of the cortex remained unaltered (Fig. 4.12a).
One implant appeared to be standing proud of the inferior border of the mandible.

Palladium
Three of the six implants were imaged adjacent to the teeth. Three implants were flattened at their cortical ends.
No alteration in bony radiodensity could be discerned in either the cortical or cancellous bone.
Two implants appeared to be standing proud of the inferior border of the mandible (Fig. 4.12b).

Gold alloy

Three of the six implants appeared imaged in direct relationship with the teeth.

In all cases no changes in radiodensity of adjacent cancellous bone were apparent.

In one case there was an increase in thickness of the cortical bone towards the cancellous bone (Fig. 4.13a).

One implant appeared to be standing proud of the inferior border of the mandible (Fig. 4.13b).

Gold

Three of the implants appeared imaged in direct relationship with the teeth.

The cortical ends of four implants exhibited distortion in the form of flattening at the cortical ends.

There were no radiographic features within either the cortical or the cancellous bone to suggest any change in radiodensity, except in the specimen shown in Fig. 4.12c, which demonstrates an apparent increase in thickness of the cortical bone towards the cancellous bone.

b) AFTER THIRTEEN WEEKS

Copper

Four of the implants were imaged in relationship with the teeth. Changes in bony architecture could be seen in all cases.

The cortical bone adjacent to three implants showed marked changes in contour, with inferior bulging of the lower border, and an associated increase in thickness of the cortex in a lamellar fashion for 10mm around the implant. Immediately adjacent to the implants, a well-defined area of increased radiolucency was observed (Fig. 4.14).

Two cases showed no increase in cortical thickness, but

a generalised ill-defined radioluceny consistent with bone lysis adjacent to the implant was observed.
One implant had become extruded from the cancellous bone, but remained in place within the cortex, which demonstrated a lamellated increase in thickness, extending for 10mm from the implant. The radiographic appearance was similar to that of a periostitis (Fig. 4.15a). In five specimens there was a generalised increase in radiolucency within the cancellous bone adjacent to the implants. The radiolucent areas had irregular and ill-defined outlines (Fig. 4.15b).

Dentozyl®

Four of the six metallic implants appeared imaged in direct relationship with the teeth.
Two cases exhibited focal radiolucencies in the cortical bone extending less than 1mm either side of the implant (Fig. 4.16a).
No changes in the density of cancellous bone were observed in any specimen (Figs. 4.16b and 4.16c).

Silver

All six implants were imaged in relationship with the teeth. One implant appeared slightly bent (Fig. 4.17a).
Two implants showed evidence of a slight decrease in radiographic density in the inferior cortex adjacent to the implant (Fig. 4.17b).
Otherwise there was no evidence of alteration in bone density in either cortical or cancellous bone (Fig. 4.17c).

Platinum

One of the six implants appeared on radiograph to be in close association with the apices of a tooth.
There was no alteration in radiographic density in either cortical or cancellous bone adjacent to the implant in any specimen (Fig. 4.18a).

The cortical end of one implant exhibited distortion in the form of flattening (Figs. 4.18b).

Palladium

All six implant images appeared superimposed on teeth.
Two of the specimens showed small circumscribed areas of increased radiolucency at the inferior margin of the cortex adjacent to the implants (Fig. 4.19a).
The remaining specimens did not exhibit any changes in radiodensity in either cortical or cancellous bone (Fig. 4.19b).

Gold alloy

Two implants appeared in close relationship with teeth.
One specimen demonstrated a small area of increased radiolucency with well-defined margins, in the inferior cortical border (Fig. 4.20b). Otherwise there was no evidence of alteration in bony density around the gold alloy implants within the cortical bone (Fig. 4.20b).
One implant appeared to be standing proud of the inferior border of the mandible.
There was a slight increase in cortical width in two specimens extending into the cancellous space along the margins of the implant (Fig. 4.20c).

Gold

Three of the implant images were in close relationship with teeth and the cortical ends of the implants exhibited distortion in the form of flattening and lipping (Figs. 4.21a and 4.21b).
In one case there was a very small area of radiolucency in the cortical bone adjacent to the implant (Fig. 4.21a).
In the other specimens there appeared to be no evidence of altered radiographic density of the bone adjacent to the gold implants (Figs. 4.21b and 4.21c).
One implant appeared to be standing proud of the lower border of the mandible.

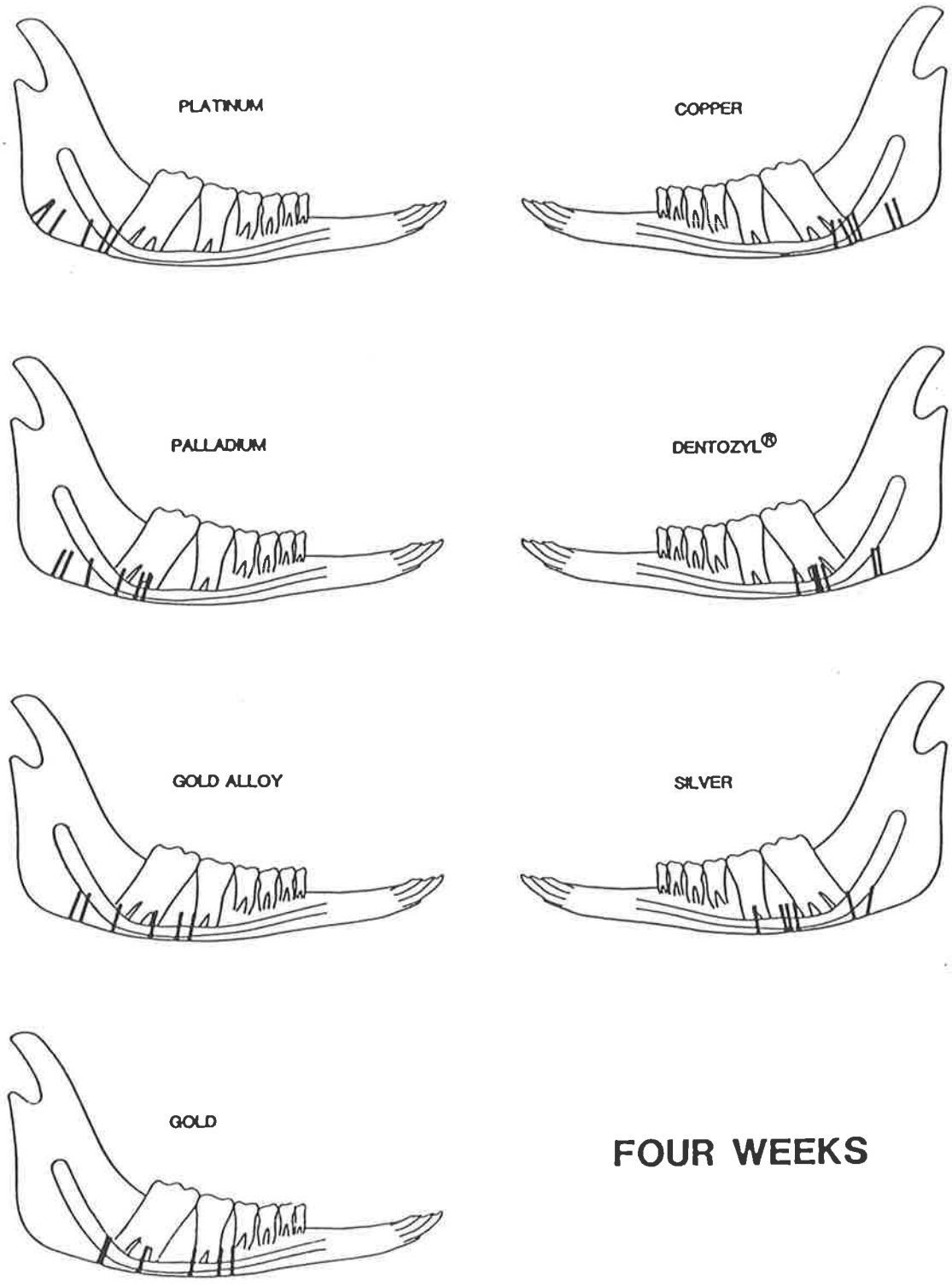


Fig. 4.7 Diagrams showing the positions of each of the metal implants in the sheep's mandibles in the first experimental group.

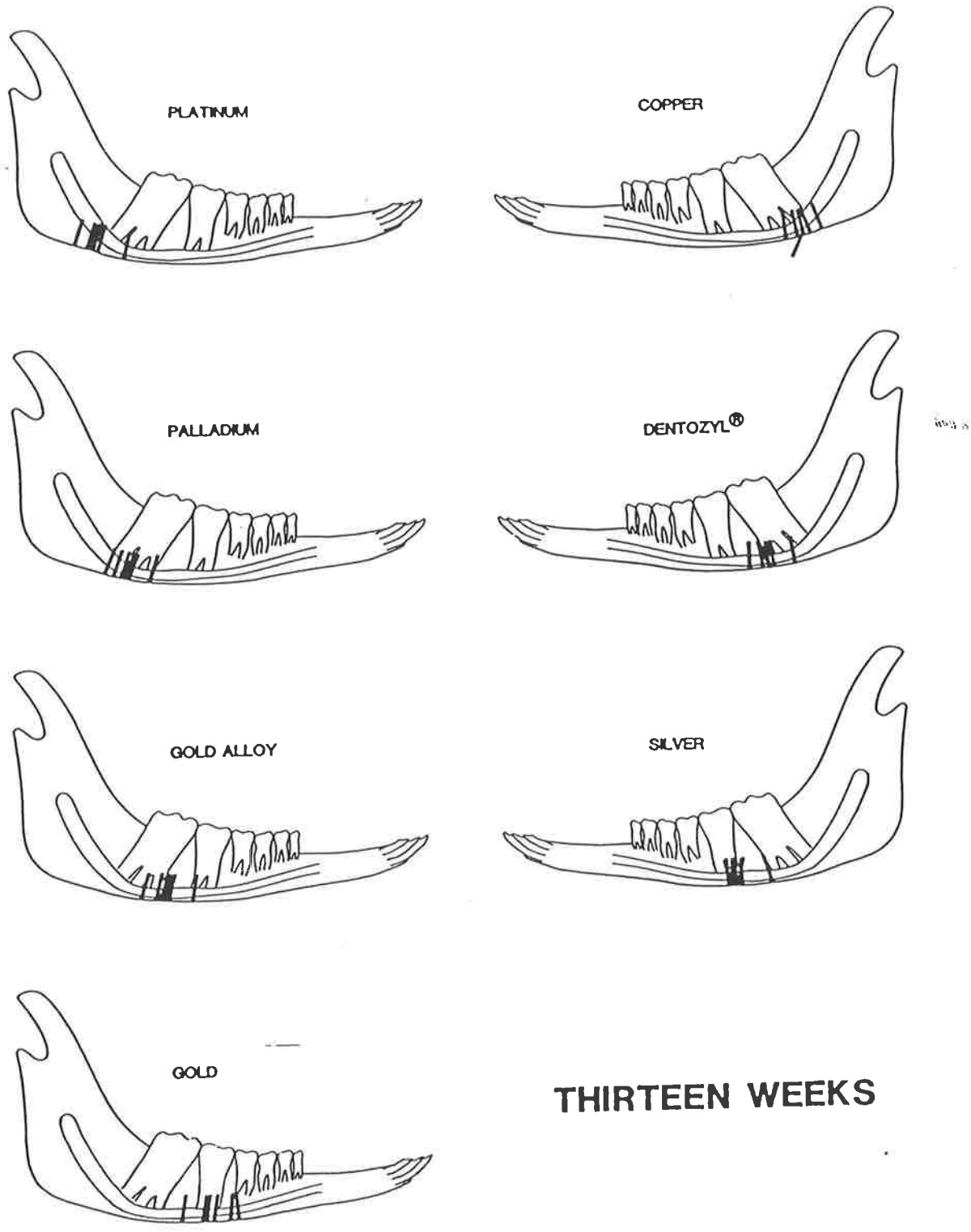


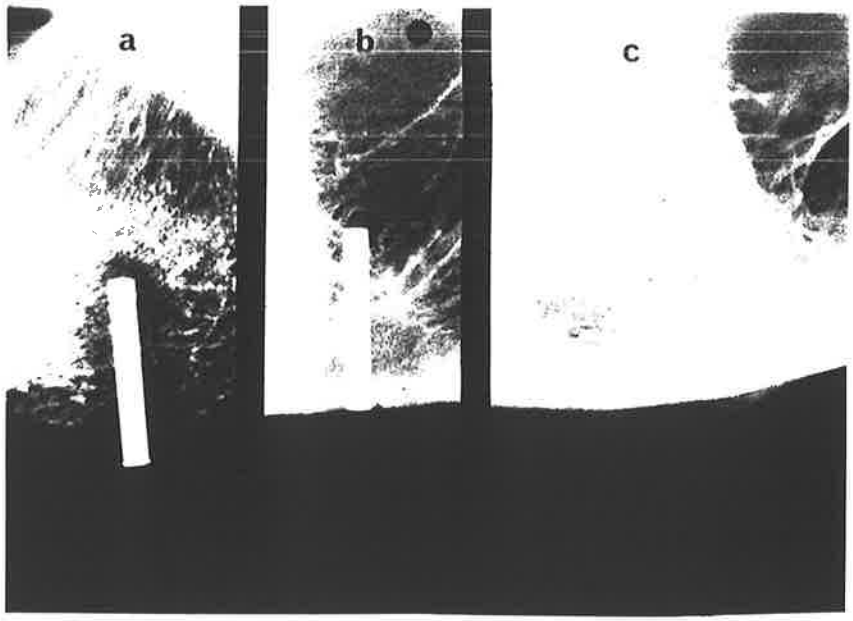
Fig. 4.8 Diagrams showing the positions of each of the metal implants in the sheep's mandibles in the second experimental group.

Fig. 4.9 **COPPER** **4 WEEKS**

Radiographs of copper implants demonstrating inferior bulging of the cortex without thickening (Fig. 4.9a); radiolucency around the implant with thinning of the cortical bone (Fig. 4.9b); and inferior bulging of the cortex with thickening (Fig. 4.9c).

Fig. 4.10 **DENTOZYL®** **4 WEEKS**

Radiographs of Dentozyl® implants after four weeks implantation. Fig. 4.10a demonstrates an apparent reaction in the cortical bone resulting in an increase in thickness (arrowed). Fig. 4.10b shows no radiographic evidence of tissue response to the Dentozyl® implant.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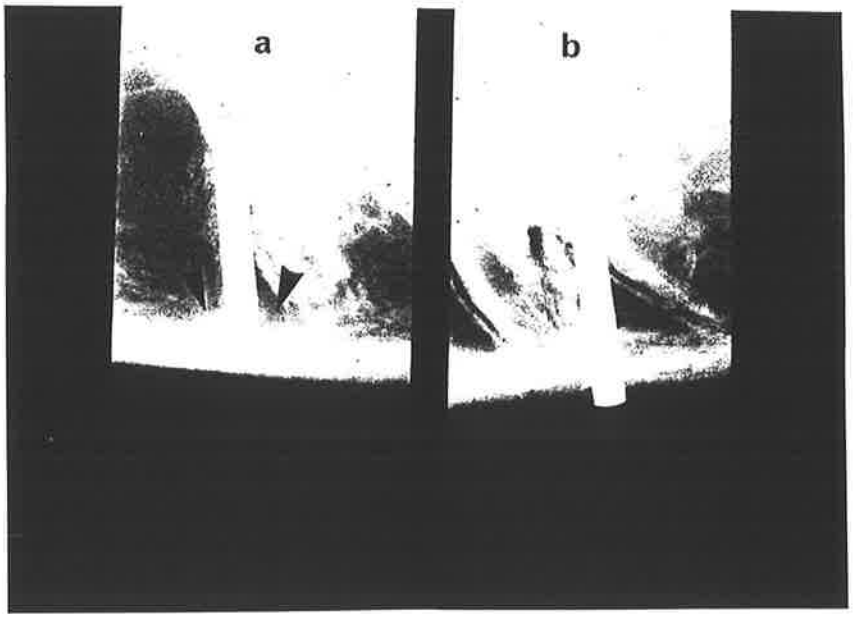
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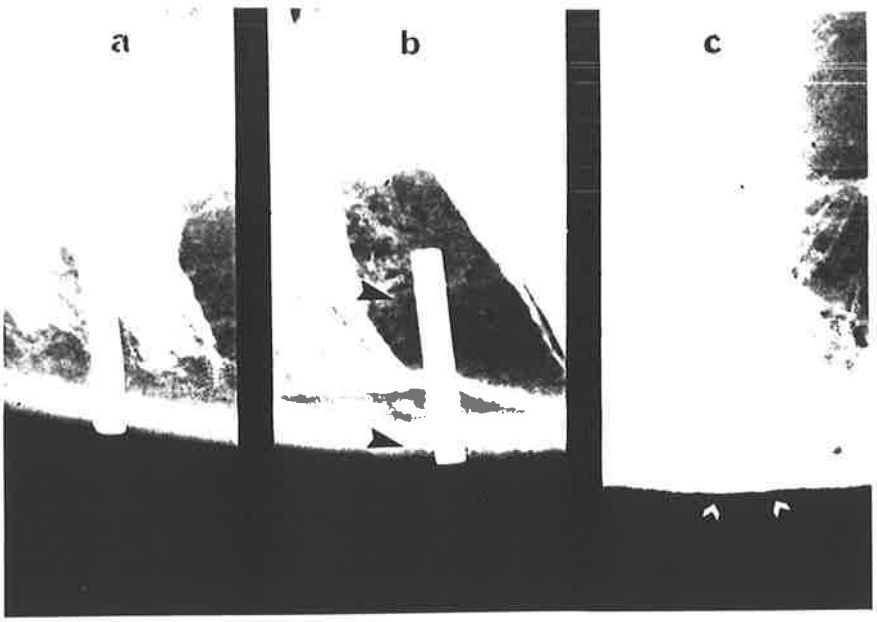
Fig. 4.11 **SILVER** **4 WEEKS**

Radiographs of silver implants after four weeks implantation. Bending of the metal can be seen in Fig. 4.11a; Fig. 4.11b demonstrates an increase in radiolucency around the implant (arrowed), and Fig. 4.11c demonstrates a reaction in the cortical bone consistent with periostitis and new bone formation at the inferior cortical margin.

Fig. 4.12 **PLATINUM, PALLADIUM, GOLD** **4 WEEKS**

4.12a: radiograph showing lack of reaction around a platinum implant. In this particular case, there is no cortex.
4.12b: radiograph showing a palladium implant. This implant is standing proud of the lower border of the mandible. There is no apparent cortical reaction.
4.12c: radiograph of tissue adjacent to a gold implant demonstrating an apparent increase in thickness of the cortical bone towards the medullary cavity (arrowed).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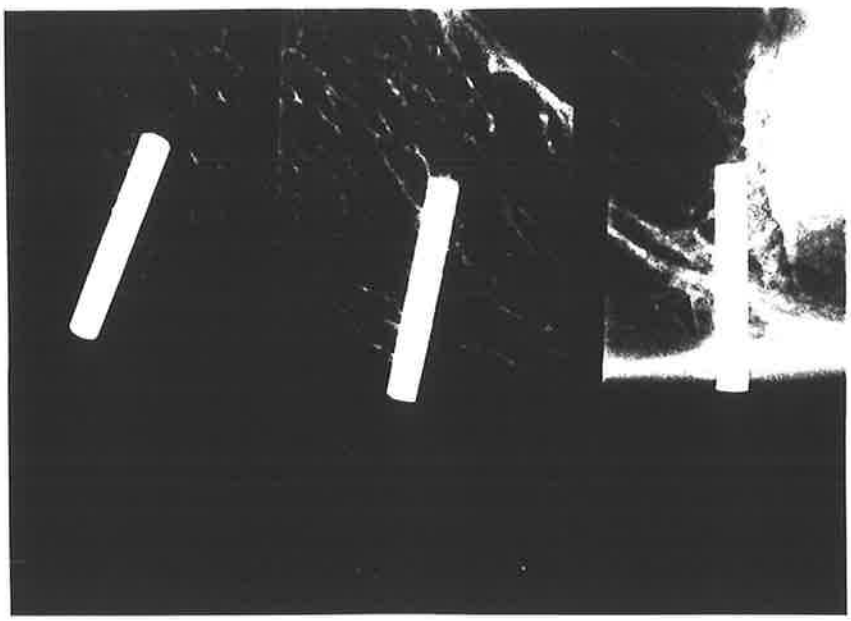

Fig. 4.13 **GOLD ALLOY** **4 WEEKS**

Radiographs of gold alloy implants and adjacent tissues after four weeks implantation. An increase in the detectable thickness of the cortical bone can be seen in Fig. 4.13a (arrowed); whereas there is no reaction obvious around the implant in Fig. 4.13b, which is also standing proud of the lower border of the mandible.

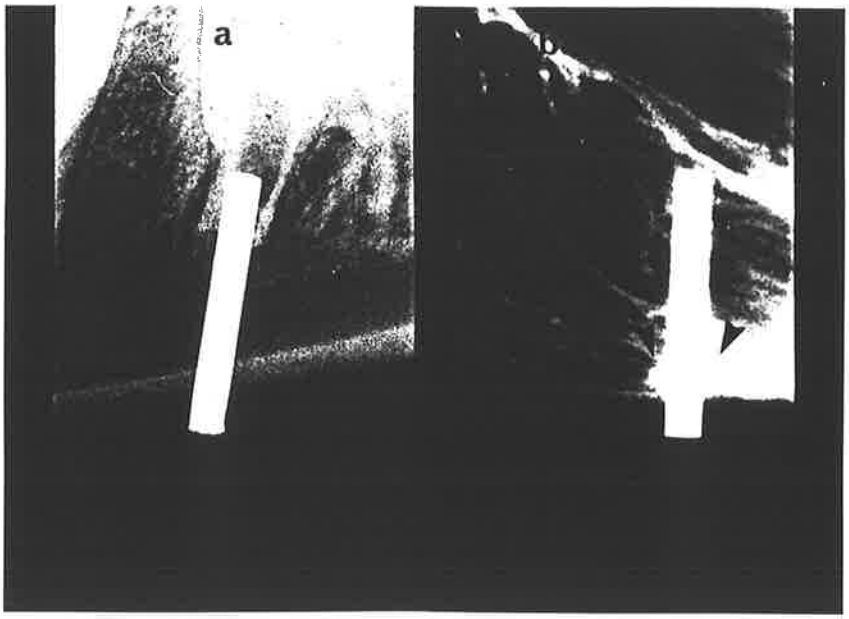
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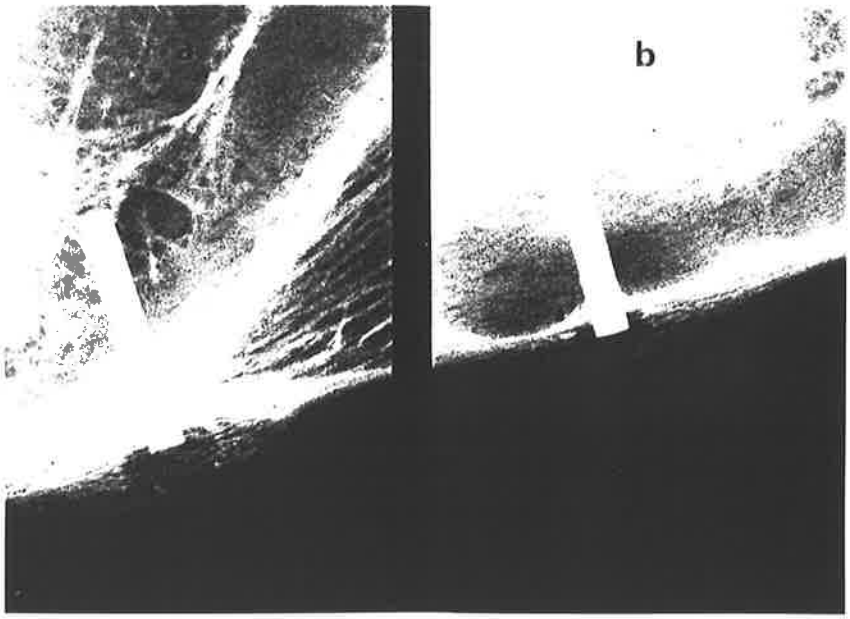
Fig. 4.14 **COPPER** **13 WEEKS**

Radiographs of two of the copper implants after thirteen weeks implantation. Both show generalised radiolucencies around the metal, with periosteal new bone formation at the lower border of the mandible.

Fig. 4.15 **COPPER** **13 WEEKS**

Fig. 4.15a demonstrates a radiograph of copper implant at thirteen weeks, partially extruded from the bone. The cortical bone is increased in thickness in a lamellated fashion. Fig. 4.15b shows a generalised radiolucency with irregular ill-defined outlines surrounding a copper implant.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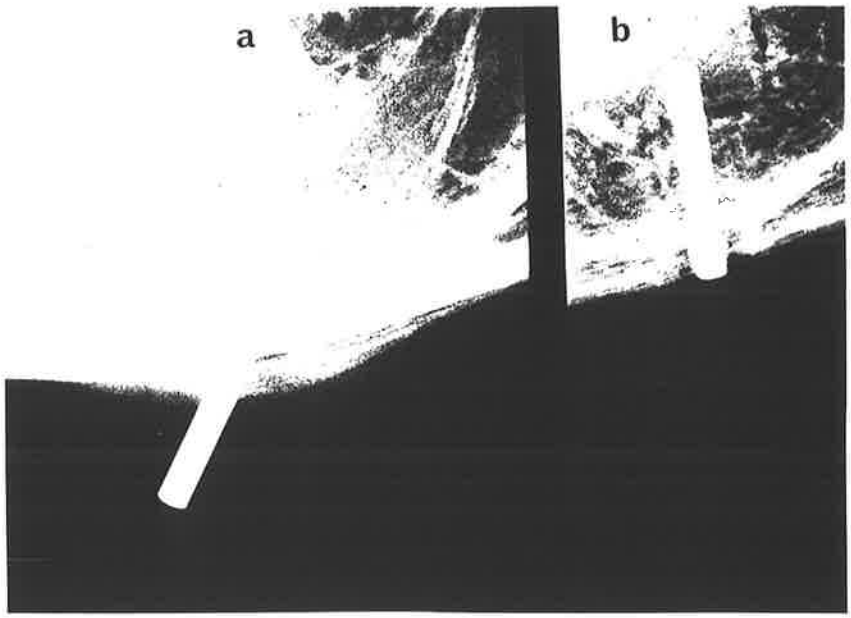
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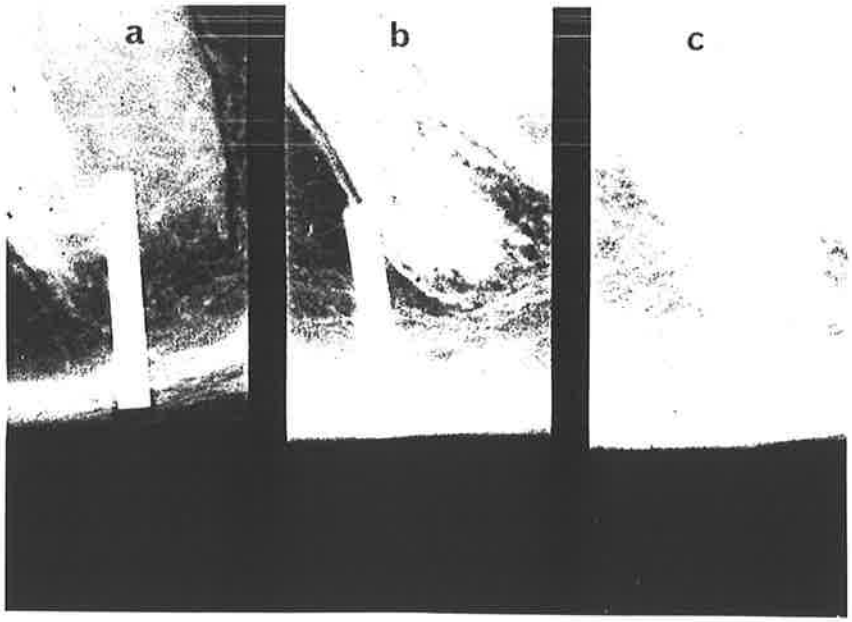
Fig. 4.16 **DENTOZYL®** **13 WEEKS**

Fig. 4.16a demonstrates a focal radiolucency in the cortical bone around a Dentozyl® implant after thirteen weeks implantation. This effect was seen in two specimens. No alteration in bony characteristics in cortical or cancellous bone can be seen in either (b) or (c).

Fig. 4.17 **SILVER** **13 WEEKS**

Radiographs of tissue and silver implants thirteen weeks after implantation, showing bending of the implant (Fig. 4.17a): a slight radiolucency at the inferior cortical border adjacent to one implant (Fig. 4.17b), and no apparent reaction around the implant in Fig. 4.17c.


a
b
c

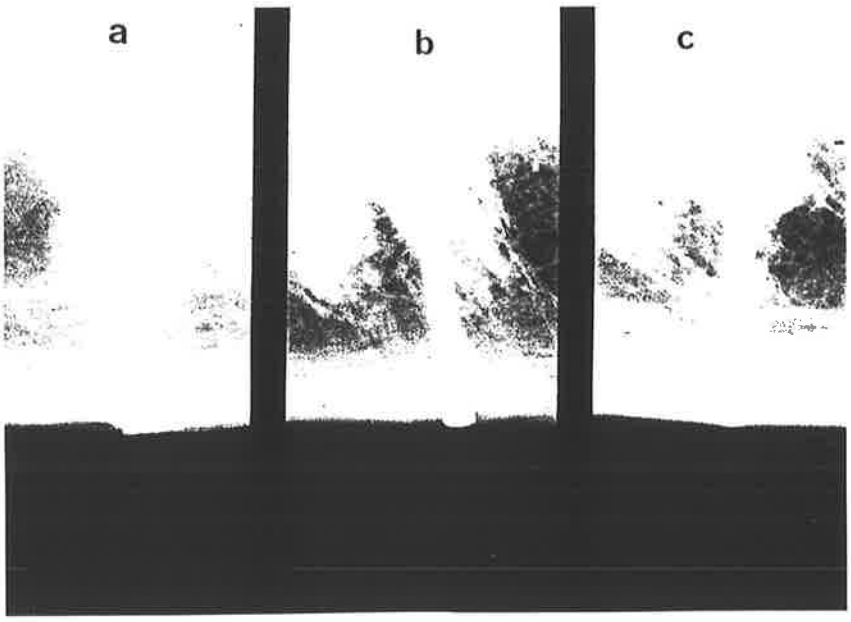
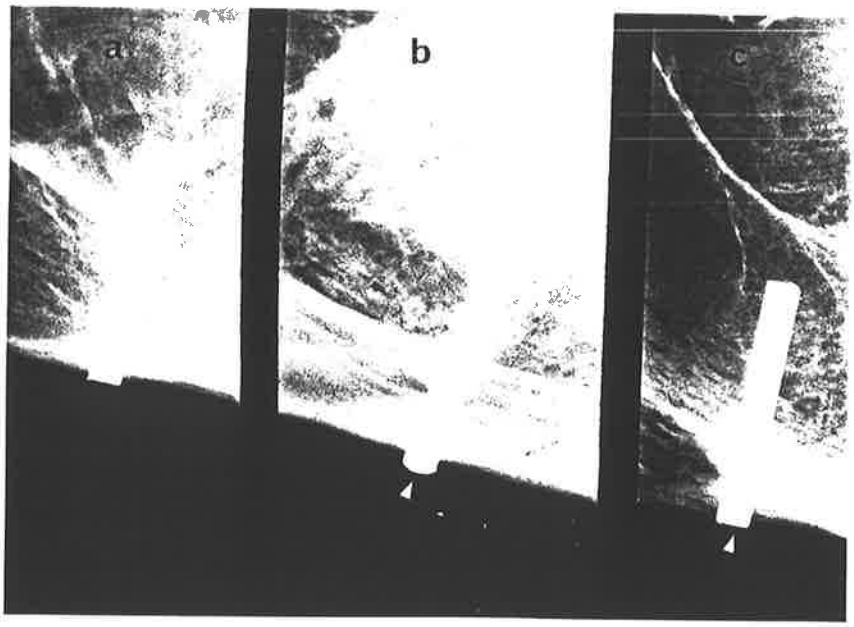

a
b
c

Fig. 4.18 **PLATINUM** **13 WEEKS**

Radiographs of platinum implants demonstrating an inert response after thirteen weeks. Fig. 4.18b shows distortion of the cortical end of the implant; minor irregularities can also be seen in the other two radiographs (arrowed).

Fig. 4.19 **PALLADIUM** **13 WEEKS**

Radiographs of palladium implants after thirteen weeks implantation. Fig. 4.19a shows a focal radiolucency in the cortical bone; this feature was seen around two implants. Fig. 4.19b shows no change in radiographic density of the bone.


a
b

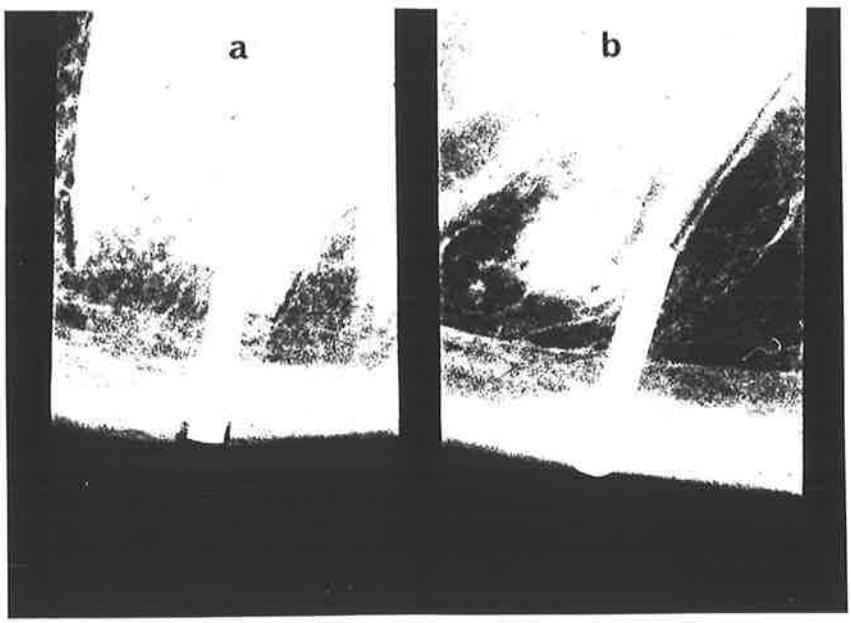
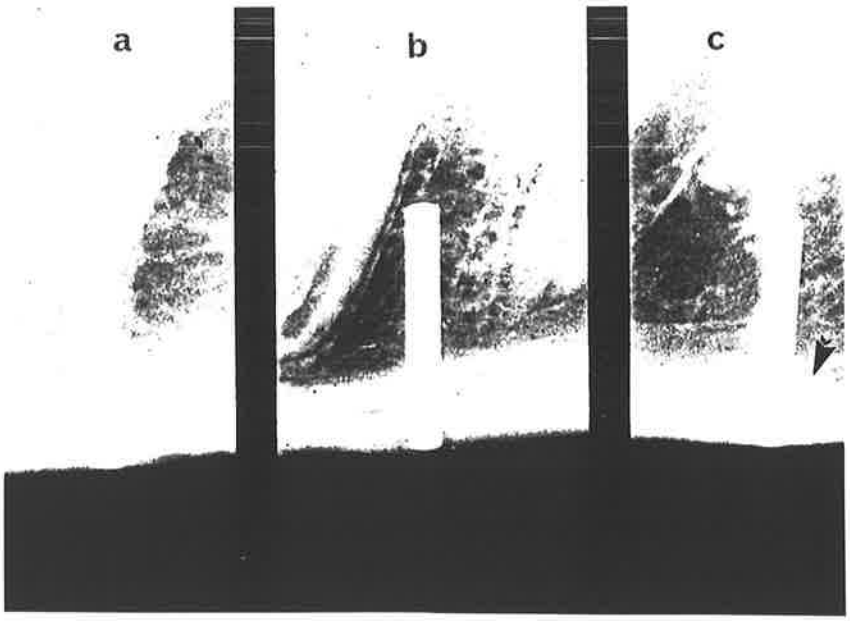

a
b

Fig. 4.20 **GOLD ALLOY** **13 WEEKS**

Radiographs of gold alloy implants demonstrating no apparent reaction (Fig. 4.20a); a focal radiolucency in the cortical bone adjacent to the implant (Fig. 4.20b); and an apparent increase in the cortical width immediately adjacent to the implant extending into the cancellous bone (Fig. 4.20c).

Fig. 4.21 **GOLD** **13 WEEKS**

Fig. 4.21a demonstrates a focal radioluceny in the cortical bone adjacent to a gold implant, seen in one specimen. Figs. 4.21b and c show no evidence of altered radiographic density in the adjacent bone.
Distortion of the cortical ends of the implants in the form of flattening and lipping can be seen in (a) and (b).


a
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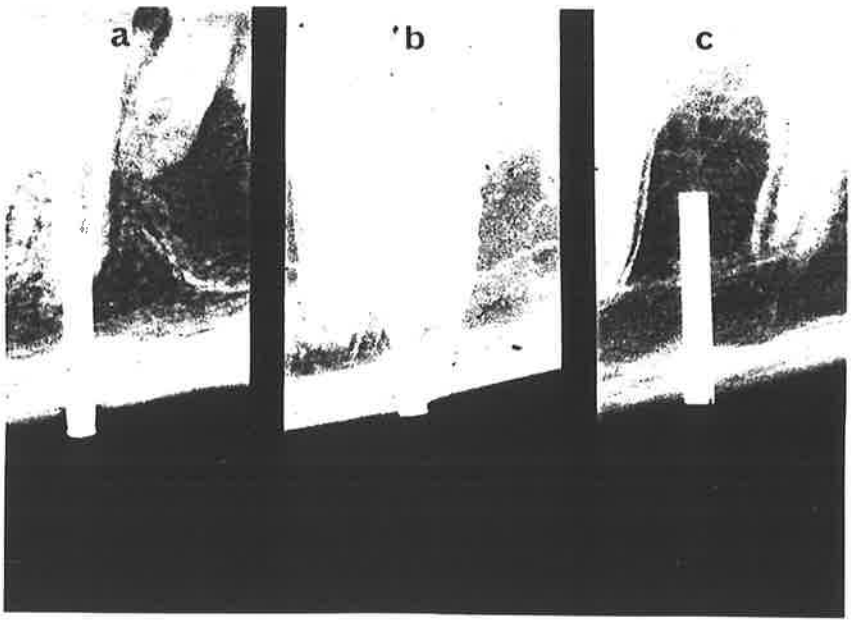

a
b
c

4.3 OPTICAL MICROSCOPY - DECALCIFIED MATERIAL

For descriptive purposes, histological assessment of each implant was made on the basis of the two zones as identified in Fig. 4.22.

Zone 1 comprised the inferior cortical bone of each specimen adjacent to the implant. Zone 2 comprised the tissue adjacent to the implant within the medullary component of the mandible; in some specimens this included dental structures and in others, areas of cortical bone from the lingual cortex.

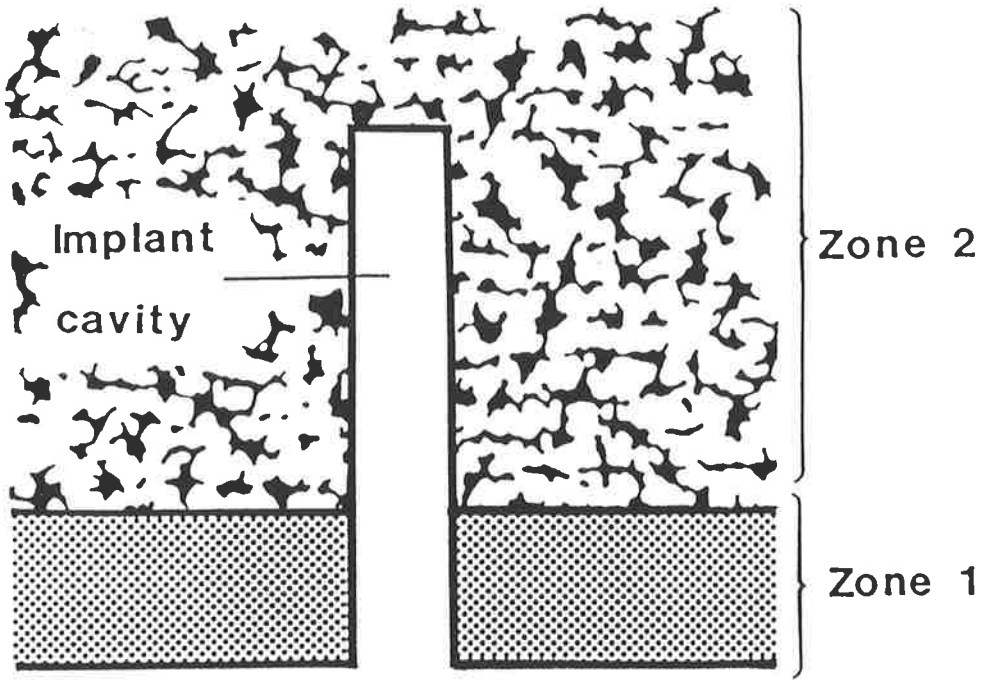


Fig. 4.22 Diagram representing the area of the mandible surrounding an implant cavity, showing the division into Zone 1 and Zone 2.

a) **AFTER FOUR WEEKS**

Copper

Zone 1

In one specimen the cortical bone was thin and ill-defined; within the other specimen the cortical bone was seen to be composed of a distinct layer of compact bone. Within Zone 1, the interface between the implant cavity and surrounding tissue was characterized by generalised abscess formation. Both acute and chronic inflammatory cells, namely polymorphonuclear leucocytes, lymphocytes and histiocytes, together with large numbers of extravasated erythrocytes were seen. Occasional bony sequestra were noted within the necrotic debris (Fig. 4.23).

Adjacent to this layer of necrotic debris, the cortical bone margin exhibited an irregular surface contour and surface osteoclastic activity.

On the inferior cortical margin, a proliferative connective tissue reaction characterised by a focal polymorphonuclear infiltrate was noted.

Zone 2

Microscopic examination of both specimens demonstrated a prominent area of necrosis immediately adjacent to the implant cavity, and surrounding the entire implant space in all sections examined. Peripheral to this necrotic zone an area of loose fibrous tissue with collagen bundles arranged parallel to the implant surface was noted (Fig. 4.24). This tissue was well delineated from the adjacent medullary contents, which were seen to consist chiefly of adipose tissue.

At the implant cavity apex of one specimen, spicules of necrotic bone were noted. Microscopic examination at higher power showed an appearance consistent with spicules of bone remaining from cavity preparation.

Microscopic examination of sections from one animal

demonstrated the presence of focal granulomas within Zone 2. These granulomas were seen in the soft tissues adjacent to the necrotic layer, deeper towards the medullary tissue. Histological examination of the granulomas revealed a variation in size and the presence of focal aggregates of histiocytes with an occasional fibrillar pattern of amorphous material (Figs. 4.25 and 4.26). No identifiable foreign body was detected.

Dentozyl®

Zone 1

Microscopic examination of Zone 1 of one specimen revealed that the interface tissue on both sides of the implant cavity consisted of a layer of fibrous tissue, peripheral to which was the cortical bone margin.
Examination of the bone surface demonstrated focal areas of osteoclastic activity and new bone formation adjacent to the fibrous tissue. Small particles of black/brown pigmented material were detected within the fibrous tissue. No overt evidence of inflammation was noted.

Examination of Zone 1 of the other specimen demonstrated a different response on either side of the implant (Fig. 4.27). On one side the appearence was similar to that described above. On the opposite side of the implant cavity no fibrous tissue was present; but immature bone formation was noted close to the interface (Fig. 4.28). The bone surface facing the implant space was irregular and cellular activity was present on the surface.
No particles of pigmented material were detected, nor was any overt evidence of inflammation seen.

Zone 2

Microscopic examination of Zone 2 of the specimens revealed the presence of a thin diffuse fibrous tissue layer interposed between the implant cavity and the

surrounding marrow tissues. The fibrous tissue blended with the adjacent marrow rather than possessing distinct boundaries (Fig. 4.29). The marrow tissue consisted principally of adipose tissue; scattered areas of extravasated erythrocytes were noted, together with the presence of an occasional lymphocyte.
Occasional trabeculae of mature bone showing evidence of new bone formation were noted within the fibro-adipose marrow close to the implant space, but not in the fibrous layer.
Within the marrow tissues adjacent to the fibrous layer the presence of focal granulomas in sections from one animal was noted; the appearance of which was similar to that described around the copper implant of the same specimen.

Silver

Zone 1

The interface between the implant cavity and the cortical bone within Zone 1 of all sections examined showed variations on opposite sides of the implant cavity (Fig. 4.30).
In both specimens, a layer of densely collagenous fibrous tissue was evident between the implant cavity and cortical bone on one side; on the other side of the implant space the fibrous tissue layer was absent, the bone appearing to abut directly the implant cavity.
The fibrous tissue was aligned with fibres parallel to the implant cavity. Brown/black staining pigmented material was evident on the surface of the fibrous tissue at the interface and in the deeper layers.
Peripheral to the fibrous tissue, the cortical bone demonstrated evidence of remodelling; the bone surface adjacent to the fibrous tissue was smooth but irregular (Fig. 4.31). Osteoclastic activity on the surface was present.

In one specimen, a large focal area of bone was present within the fibrous capsule and appeared to abut the implant cavity. On the interface of this bone with the implant cavity, much densely staining particulate matter was evident. Examination of multiple sections failed to show any fibrous tissue on the other side of the implant cavity within Zone 1; the tissue in one specimen was seen to be composed of cortical bone demonstrating a smooth surface at the interface with the implant cavity. There was no evidence of new bone matrix formation on this bone surface (Fig. 4.32).

Zone 1 of the other specimen demonstrated an irregular bony surface immediately adjacent to the implant cavity, with focal areas of fibrous tissue contained within depressions in the bony surface.

At the inferior cortical margin, an area of bone resorption and replacement with fibrous tissue was evident, together with bony activity demonstrated by an area of altered staining pattern. Towards the medullary cavity, the surface of the bone contained much densely staining particulate matter.

No overt evidence of inflammation was seen in Zone 1 of either specimen.

Zone 2

Zone 2 in both specimens consisted of a well-defined fibrous tissue layer of varying thickness between the implant surface and medullary contents. Detailed examination revealed a condensed layer at the actual interface, with densely packed collagen fibres aligned parallel to the implant cavity. Adjacent to the capsular zone the medullary tissue was composed principally of adipose tissue (Fig. 4.33).

Focal areas of haemorrhage were seen within the fibrous layer adjacent to the implant cavity, as were prominent deposits of pigmented particulate material. Some of the latter material was intra-cellular and had an appearance

consistent with haemosiderin; but adjoining sections stained with Prussian Blue (Appendix VI) failed to demonstrate the presence of this pigment.

Peripheral to the fibrous capsule, focal areas of mature trabecular bone were shown to have maintained their vitality, as evidenced by the presence of osteocytes within their lacunae.
Examination of one specimen (Fig. 4.34) showed that the implant had penetrated the pulp of a tooth which showed signs of apical repair.
Scattered areas of inflammatory cells were seen in both specimens examined, and in one animal, focal granulomas were noted adjacent to the fibrous capsule, identical in appearance to those seen adjacent to the copper implant in the same animal.

Platinum

Zone 1

Microscopic examination of Zone 1 showed variations between the specimens.
In sections from one animal, no identifiable cortex was evident; however, a thin fibrous connective tissue layer was present between the implant cavity and trabeculae of mature bone, the latter showing evidence of surface bone deposition (Fig. 4.35).
In the other specimen, examination revealed focal areas of fibrous tissue between the implant cavity and cortical bone in Zone 1. In areas devoid of fibrous tissue, new bone formation was evident within the cortical bone and a layer of osteoblasts was present on the surface of the bone nearest the implant cavity (Fig. 4.36). New bone formation was also present peripheral to the fibrous tissue, and in some cases extended close to the implant space.
Intra-cellular particulate matter was present at the

interface , within the fibrous tissue itself, and some distance away from the cavity, within the nutrient channels in the cortical bone.

There was no overt evidence of any inflammation present within Zone 1 in any of the sections examined.

Zone 2

Low power microscopic examination of sections from both specimens revealed a very thin layer of condensed fibrous tissue at the interface between the implant cavity and surrounding medullary tissue. Focal areas of condensation were present, with fibres aligned parallel to the implant cavity. In all areas however, the fibrous layer was very thin and the medullary contents, chiefly adipose tissue, were seen almost to abut the implant space.

Several bony trabeculae were noted in close proximity to the implant space at the apex. Detailed examination of the interface showed variable patterns; some trabeculae were lined by a thin layer of fibrous connective tissue; other trabeculae were seen almost to abut directly the implant cavity (Figs. 4.37 and 4.38).

Within the capsule, densely staining particulate matter was present. Peripheral to the fibrous capsule, scattered areas of extravasated erythrocytes were seen.

There was no overt evidence of inflammation in any section examined; however one specimen exhibited the presence of focal granulomas within the fibrous tissue in Zone 2 , the appearance of which was similar to that seen around the copper implant in the same animal.

Palladium

Zone 1

Microscopic examination of Zone 1 revealed the presence of a prominent layer of irregularly orientated fibrous

connective tissue between the implant cavity and the adjacent cortical bone in both specimens. The cortical bone showed evidence of new bone formation and osteoclastic resorption on those surfaces facing the implant cavity.
Examination of one specimen at a gross level had shown it to be covered by a layer of tissue; microscopic examination of this specimen revealed a layer of fibrous tissue continuous with that adjacent to the long axis of the implant cavity.
There was no overt evidence of inflammation seen in any of the sections examined; nor was any particulate matter present.

Zone 2

Microscopic examination of Zone 2 revealed variations in the nature of tissue between the implant cavity and surrounding medullary tissues.
In one specimen examined, a prominent zone of fibrous connective tissue between the implant space and surrounding medullary tissues was evident. This fibrous tissue varied in thickness along the length of the implant and demonstrated focal areas of surface condensation.
Bony spicules abutting the implant cavity showed evidence of activity in the form of apposition, with osteoblasts lined up along the surface of the bone (Fig. 4.39).
Finely dispersed intra-cellular particulate matter was present within the fibrous capsule.
No overt evidence of inflammation was present, but focal granulomas along the peripheral edges of the fibrous tissue within Zone 2 of this specimen were seen. Their appearance was similar to that described around the copper implant in the same animal.

In the other specimen, the apical portion of the implant was situated within the pulp of the tooth root (Fig.

4.40). Large numbers of variable sized dentinal spicules showing evidence of mineralised tissue matrix formation were seen both within the pulp of the tooth and along the lateral margins of the implant space (Fig. 4.41). Some of these dentinal chips were mixed with osteoid-like material directly abutting the implant cavity. The pulp itself appeared fibrotic and largely devoid of odontoblasts. An additional finding was the presence of a prominent peri-implant zone of coarse fibrillar bony material in Zone 2, between the cortical bone of Zone 1 and the tooth root. Detailed examination of this material and its relationship to the implant cavity showed areas where a very thin soft tissue layer could be identified between the implant space and the bone, and also areas where the bony tissue appeared to abut directly the implant space. The interface here was characterised by the presence of a basophilic line within the matrix and by finely particulate pigmented material, consistent with metallic particles, in the fibrous tissue.
No overt evidence of any inflammation was present in any section of this specimen examined.

Gold alloy

Zone 1

Microscopic examination of sections from one animal revealed a thin layer of vascular fibrous tissue of varying thickness between the implant cavity and the cortical bone in Zone 1 (Fig. 4.42). No definite alignment of the fibres was noted. Finely dispersed particulate matter was present within the fibrous tissue layer, but no overt evidence of inflammation was seen (Fig. 4.43). Extravasated erythrocytes were however a consistent finding in this layer.
The periosteal end of the implant in this specimen had been covered with tissue when examined at a macroscopic

level; examination of this tissue under the microscope demonstrated the presence of cellular fibrous tissue continuous with that adjacent to the long axis of the implant. A large focal area of coarse mineralised tissue was also present within the fibrous tissue.

The surface of the cortical bone peripheral to the fibrous tissue was seen to be smooth but irregular, and appeared to abut the implant cavity directly on some sections examined. The presence of osteoblastic activity and new bone apposition on pre-existing bone was demonstrated at the junction with the fibrous tissue.

Examination of Zone 1 of the other specimen was complicated by tangentially cut sections giving the appearance of the implant cavity having been completely covered by bone. However, those parts identifiable in Zone 1 showed evidence of fibrous tissue interposed between the implant space and the surrounding bone.

Zone 2

Observation of Zone 2 in both specimens demonstrated the presence of a fibrous tissue layer of varying thickness, being very thin in places. A cellular, condensed fibrous layer was present at the interface itself. No overt evidence of inflammation was present in either specimen. Densely staining particulate material, both intra-cellular and extra-cellular, was observed within the layer of fibrous connective tissue (Fig. 4.44).

The apex of the implant in one specimen was seen to have penetrated the inferior alveolar nerve, which did not exhibit any sign of necrosis.
Bony apposition on spicules of mature bone were present peripheral to the nerve. Also seen within the fibrous capsule of this specimen were focal granulomas, the appearance of some of which was similar to those seen

around the copper implant from the same animal. Other granulomas were seen to contain mineralised tissue.

Examination of sections from the second animal showed that the implant had penetrated the dentine and pulp of a tooth root. Tissue responses in this area were seen to be similar to that previously described for one of the palladium implants. For most of the implant interface, the mineralised tissue matrix was seen to abut the implant cavity directly; focal areas were present where a lining of cells one layer thick was present along the interface.

Gold

Zone 1

Microscopic examination of sections from one of the specimens demonstrated the presence of a thin layer of fibrous tissue, with no definite orientation, interposed between the implant cavity and the cortical bone in Zone 1. In several sections examined, this fibrous layer was absent, and the cortical bone appeared to abut the implant cavity directly (Fig. 4.45). The surface of this cortical bone was smooth and did not appear to exhibit signs of bone matrix apposition or remodelling.
Around the implant cavity at the inferior cortical border, an area of cellular fibrous connective tissue was seen, with no definite orientation of the fibres. Contained within this zone of connective tissue were focal aggregates of coarse fibrillar mineralised tissue with osteoblasts on the surface. Isolated areas of pigmented particulate material were present but no overt evidence of inflammation was seen in any section examined.

Examination of sections from the other specimen was complicated by tangentially cut sections, giving the

appearance of the implant cavity having been completely covered by bone. However, those parts identifiable within Zone 1 showed evidence of fibrous tissue interposed between the implant space and surrounding bone.

Zone 2

Microscopic examination of Zone 2 in sections revealed that both gold implants had penetrated teeth. One specimen was seen to be completely surrounded by pulp and dentine in Zone 2. At the apex of the implant cavity numerous spicules of dentine were seen, surrounded by mineralised tissue matrix, which extended along the long axis of the implant on one side, directly abutting the implant cavity, similar to the appearance in the gold alloy specimen. Along the pulpal-most aspect of the dentine itself, odontoblasts were observed with a lining of predentine.

Along the opposite side of the implant cavity a thin layer of cellular fibrous tissue was evident interposed between the cavity and underlying dentine. Scattered areas of pigmented particulate material were present in the deeper layers of this fibrous tissue, and also in the medullary contents peripheral to the tooth.

The medullary contents consisted chiefly of vascular adipose tissue demonstrating some fibrosis, and bone deposition was seen to have occurred on mature trabeculae.

Examination of the other specimen showed that the implant had only pared the dentine of the external aspect of the tooth root. The appearance of the dental tissues adjacent to the implant cavity was seen to be similar to that described above.

Along the other side of the implant cavity an ill-defined fibrous zone of varying thickness was present between the cavity and the medullary contents, which

consisted chiefly of adipose tissue (Fig. 4.46). Several mature bone trabeculae with deposition of immature bone along the surfaces were seen peripheral to the fibrous capsule. Osteoblasts were present along the surface of these trabeculae.

Several macrophages were noted around the dentine spicules, but otherwise there was no overt evidence of any inflammation. Focal granulomas were present within the periphery of the fibrous tissue; these had an appearance similar to those seen and described around the copper implant.

b) AFTER THIRTEEN WEEKS

Copper

Zone 1

Microscopic examination of sections from both specimens demonstrated the presence of much necrotic debris at the interface of the implant cavity. Peripheral to this, a thick band of fibrous tissue, with fibres aligned parallel to the implant cavity, and in places infiltrating the cortical bone, was seen. Within this fibrous capsule, and also within the debris at the interface, bony sequestra were noted (Fig. 4.47).
Peripheral to the band of fibrous tissue, the cortical bone margin was seen to have an irregular rough surface consisitent with resorption. The inferior cortical margin within one specimen also had an appearance consistent with bone loss.

Zone 2

Examination of this area in both sections revealed a thick capsule of fibrous tissue immediately adjacent to the implant cavity. The tissue was loosely arranged with fibres running parallel to the implant cavity.

Metallic debris was also present along the actual interface. Some of the bony trabeculae peripheral to this fibrous band exhibited resorption at the surface adjacent to the fibrous tissue.

In sections from one animal, the implant was seen to have penetrated a tooth: at the apex of the implant cavity many dentine spicules could be seen and along one side of the implant cavity resorption of the dentine was apparent, directly abutting the implant cavity.
Along the implant cavity at the opposite side, a band of epithelium, approximately six cells thick, was seen between the implant cavity itself and the underlying fibrous tissue.

Dentozyl®

Zone 1

Examination of this area in sections from both animals demonstrated the presence of isolated areas of thin fibrous tissue between the implant cavity and the cortical bone of Zone 1 (Fig. 4.48). Extravasated erythrocytes were seen within the islands of fibrous tissue. The majority of the interface within Zone 1 however, appeared to be composed of cortical bone directly abutting the implant cavity, with lamellae running parallel to the long axis of the implant cavity. Sections from one specimen exhibited an artifactual splitting of this lamellar bone from the pre-existing cortical bone, the lamellae of which were running parallel to the inferior cortical margin (Fig. 4.49).
Scattered areas of finely particulate matter consistent with metallic debris were evident in both specimens, both along the actual interface and within the nutrient channels of the cortical bone.
The implant in one specimen, when examined with the naked eye, was noticed to have been completely covered

with new tissue: examination at a microscopic level showed that this tissue was composed of new lamellar bone with the lamellae running parallel to the cortical bone of the lower border of the mandible (Fig. 4.50).

Zone 2

Tissue response was seen to vary in Zone 2 between the specimens, due to the varying nature of the tissues encountered at implantation.

Within one specimen, the implant was seen to be situated very close to a tooth root along one side. The surface of this tooth closest to the implant cavity exhibited some resorption and replacement with fibrous tissue.
At the apical two thirds of the implant cavity and at the apex itself, an area of bone apparently abutting the implant cavity was evident; cells were present along the bone surface furthest from the implant, together with an eosinophilic layer along the surface, features consistent with bone deposition.
At the third of Zone 2 nearest to Zone 1, the interface consisted of a thin ill-defined fibrous capsule with underlying adipose tissue. Fibres were aligned parallel to the long axis of the implant cavity. Present in this tissue were scattered extravasted erythrocytes and some areas of finely particulate densely staining material, consistent with metallic debris.

The other specimen, when examined, demonstrated an ingrowth of trabecular bone towards the medullary cavity (Figs. 4.51 and 4.52). These trabeculae had the appearence of immature bone, and osteoblasts were present on the surface. Interposed between the trabeculae and the implant cavity was an ill-defined layer of fibrous tissue with a condensed layer at the interface itself. The fibrous tissue was slightly thicker than that seen in the previous specimen, and the

underlying tissue in this second specimen was composed of fibro-adipose tissue.
The apex of the implant cavity was seen to have penetrated the lingual cortical plate (Fig. 4.52); bony ingrowth towards the implant cavity; a thin layer of fibrous tissue containing metallic particles lined the cavity.
The inferior alveolar nerve was seen along one side of the implant cavity in this specimen; no evidence of necrosis was seen.

No overt evidence of inflammation was seen in any of the sections examined.

Silver

Zone 1

Microscopic examination of sections from both specimens demonstrated intermittent areas of fibrous tissue at the interface of the implant cavity and the cortical bone. The fibrous tissue varied in thickness (Fig. 4.53) and contained much densely staining particulate material, consistent with metallic debris.
Peripheral to these areas of fibrous tissue, the cortical bone was seen to have a smooth regular surface, with lamellae running parallel to the implant cavity. Within the nutrient channels in the cortical bone, metallic debris was present.

Areas of cortical bone devoid of a fibrous tissue covering were also seen at the interface with the implant cavity; the bone surface here was smooth, with lamellae running parallel to the long axis of the implant cavity. This altered lamellar pattern appeared to stain more densely than the pre-existing cortical bone (Fig. 4.54).

At the inferior cortical margin of one specimen, an area of apparent bone loss was present, with a covering of fibrous tissue.
Sections from the other specimen revealed an area of thickened fibrous tissue between the cortical bone and periosteal space at one edge of the implant cavity.

Zone 2

Microscopic examination of sections from both specimens revealed a thick layer of fibrous tissue surrounding the implant cavity in Zone 2. In one specimen, this was of regular thickness, peripheral to which was adipose tissue; within the other specimen, the thickness was seen to vary, with fibro-adipose tissue lying peripherally. A condensed layer immediately adjacent to the implant cavity was present in all sections examined.
Sections from one specimen exhibited islands of bone, with smooth regular outlines, appearing to be in surface apposition with the implant cavity. The apex of the implant in this specimen was seen to be in very close proximity with the apex of a tooth root, the latter demonstrating evidence of resorption and replacement with fibrous tissue. Metallic debris was present both on the surface and within the fibrous capsule.

Sections from the second specimen revealed trabeculae of bone peripheral to the fibrous capsule and some bony activity in the apical zone, the structure of which was consistent with woven bone. Areas of extravasated erythrocytes were found in the peripheral adipose tissue.

Platinum

Zone 1

Microscopic examination of sections from both specimens revealed that the interface tissue was composed mainly

of bone, with isolated areas of fibrous tissue being present (Fig. 4.55).
The surface of the cortical bone both abutting the implant cavity and peripheral to the fibrous tissue was smooth and regular, with a lamellar pattern running parallel to the implant cavity. Osteoblasts were situated on the surface of the bone adjacent to the islands of fibrous tissue.
Contained within the nutrient channels within the cortical bone, and also within the fibrous tissue, finely dispersed densely staining particulate material was seen, consistent with metallic debris.

Macroscopic examination of one specimen had shown the implant to be covered with tissue; microscopic examination of this area revealed new bone formation.
Macroscopic examination of the other specimen had revealed a cuff of new tissue around the implant which had been standing proud of the bone; microscopic examination of this area showed new bone and fibrous tissue formation.

No evidence of inflammation was seen in any section examined.

Zone 2

Examination of sections from both specimens revealed a thin ill-defined fibrous capsule with a condensed surface layer surrounding the implant cavity. Isolated spicules of bone were evident within the fibrous tissue, as was metallic debris.
Peripheral to the fibrous capsule were the normal medullary contents; mainly adipose tissue in one specimen, and trabeculae of bone and fibro-adipose tissue in the other. The bony trabeculae showed evidence of new bone deposition on the surface, and in one area the bone appeared to abut the implant cavity directly.

Areas of metallic debris were also evident in the adipose tissue peripheral to the fibrous capsule.

The inferior dental nerve was seen to be in close proximity to the implant cavity in both specimens; no evidence of necrosis was present, although an irregular area of fibrous tissue was present between the nerve and the implant cavity in one specimen.

The presence of woven bone close to the apex of the implant cavity was noted in one specimen.
Isolated areas of extravasated erythrocytes were a consistent finding in the tissue of all sections examined; but no overt evidence of inflammation was seen.

Palladium

Zone 1

Microscopic examination of sections from both specimens revealed slight variations in tissue response in Zone 1. In one specimen, the implant cavity was seen to be lined by a very thin layer of fibrous tissue which contained metallic debris. The cortical bone peripheral to this tissue exhibited a smooth regular surface with lamellae parallel to the implant cavity.

Examination of the other specimen demonstrated only focal areas of fibrous tissue with metallic debris on the surface at the interface. Elsewhere, there appeared to be a direct relationship between the implant cavity and the cortical bone. The surface of the bone possessed a rough irregular surface and an altered lamellar pattern, running parallel to the implant cavity. Within the nutrient vessels in the cortical bone of Zone 1, finely dispersed densely staining particulate material was present.

A focal proliferation of non-inflamed fibrous tissue was present around the implant cavity at the inferior cortical margin.

Zone 2

Zone 2 was characterised by the presence of a thin ill-defined fibrous capsule with focal areas of condensation surrounding the implant cavity.
In both specimens, trabeculae of bone were present close to the implant cavity, separated from the latter in most instances by a very thin layer of fibrous tissue. Sections from one specimen demonstrated surface deposition on the bone surface adjacent to the implant cavity; deposition and the presence of osteoblasts on the surface of the bone distant from the implant cavity were noted in sections from the other specimen.

One specimen was seen to have penetrated the inferior dental nerve; although no evidence of necrosis was seen, fibrous tissue infiltration between the nerve bundles was present, together with finely dispersed metallic debris.

The apex of the implant cavity of one specimen was noted to have penetrated the lingual cortical plate; examination of this area revealed immature bone directly abutting the implant cavity, with a layer of metallic debris at the actual interface (Fig. 4.56).

Gold alloy

Zone 1

Microscopic examination of sections revealed variations in tissue response between the specimens.

Macroscopic examination of one specimen had revealed a cuff of new tissue extending around the neck of the

implant that had been standing proud of the inferior cortical border. Microscopic examination of this area revealed a zone of new bone formation with lamellae extending from the inferior cortical margin, similar to that seen around the platinum and Dentozyl® implants (refer to Fig. 4.50).
Within the substance of Zone 1, focal areas of very thin fibrous tissue were evident adjacent to the implant cavity, peripheral to which was the cortical bone with a smooth regular surface. In areas devoid of fibrous tissue, direct bony abutment to the implant space was noted; the cortical bone possessing a smooth regular surface, and evidence of bony remodelling adjacent to the implant cavity (Fig. 4.57). Isolated metallic debris was seen along the actual interface of the tissue and implant space.

Radiographic examination of the second specimen had shown a focal radiolucency around the gold alloy implant. Microscopic examination of Zone 1 in this specimen revealed an area of bone loss at the inferior cortical margin and a vascular fibrous capsule of regular thickness between the implant cavity and peripheral cortical bone (Fig. 4.58). There was no definite orientation to the collagen fibres. Focal areas of bone with surface depositon were present within the fibrous capsule, as was finely dispersed metallic debris.
The cortical bone margin was seen to have a smooth surface and altered lamellar pattern.
Focal bone deposition and osteoblasts were evident on the surface of the bone adjacent to the fibrous tissue.

Zone 2

Microscopic examination of Zone 2 in both specimens revealed the presence of a thin ill-defined fibrous capsule with minimal surface condensation at the inter-

face. Metallic debris was present within the fibrous capsule.
Peripheral to the fibrous capsule, adipose tissue was present in parts, as were bony trabeculae with bone deposition on the surface (Fig. 4.59). Although present in both specimens, the trabeculae were more numerous in one specimen, where they were seen to be present along the length of the implant in Zone 2, separated from the latter by only a very thin layer of fibrous tissue.
One implant had penetrated the inferior dental nerve; no evidence of necrosis was seen, but a thin fibrous tissue infiltation was noted.

Gold

Zone 1

Radiographic examination of one specimen had shown a focal radiolucency around the gold implant. Microscopic examination of this specimen showed a layer of fibrous tissue surrounding the implant cavity. The fibres were loosely arranged, with no regular orientation. Metallic debris was contained within the fibrous capsule.
Peripheral to the fibrous capsule, the cortical bone demonstrated variations in tissue response at either side of the cavity. Along one edge, the appearance of the bone was that of the pre-existing bone, with focal areas of resorption noted (Fig. 4.60).
Along the opposite side of the implant cavity, the lamallae were parallel to the long axis of the cavity, with some evidence of bone deposition apparent.

Macroscopic examination of the other specimen had shown a layer of tissue over the implant, which had been finished flush with the bone surface at the time of implantation. Microscopic examination of this area demonstrated a layer of dense fibrous tissue aligned parallel to the lower border of the mandible.

Focal areas of fibrous tissue were evident within the cortical bone of Zone 1 immediately adjacent to the implant cavity. Contained within these areas, and also within the nutrient channels in the cortical bone, was finely dispersed metallic debris.
Peripheral to the fibrous tissue, the cortical bone surface possessed a smooth regular surface with a lamellar pattern parallel to the long axis of the implant cavity.

Zone 2

The interface at the surface of the implant cavity in sections from both specimens was characterised by a thin ill-defined fibrous capsule blending with the underlying fibro-adipose tissue, with no surface condensation apparent. Metallic debris was present both on the surface and within the substance of the fibrous capsule. Trabeculae of mature bone were present in both specimens peripheral to the fibrous capsule; in one specimen no evidence of recent bony activity was apparent, whereas in the second specimen, evidence of resorption on the surface closest to the fibrous tissue, and deposition on the surface distant from the fibrous capsule was noted.

One specimen had penetrated the inferior dental nerve on implantation; apart from some fibrous infiltration of the perineurium, the nerve appeared intact.

Around the apex of the implant cavity in one specimen, bone from the lingual cortical plate was present, and was seem to abut directly the implant cavity.

No overt evidence of inflammation was seen in any section examined.

Fig. 4.23 **COPPER** **4 WEEKS**

Photomicrograph of Zone 1 adjacent to the implant cavity (IC), showing bony sequestra (S), and necrotic debris (D). Peripheral to the sequestra, fibrous tissue (F) can be seen, containing inflammatory cells.

H&E
Original magnification x33

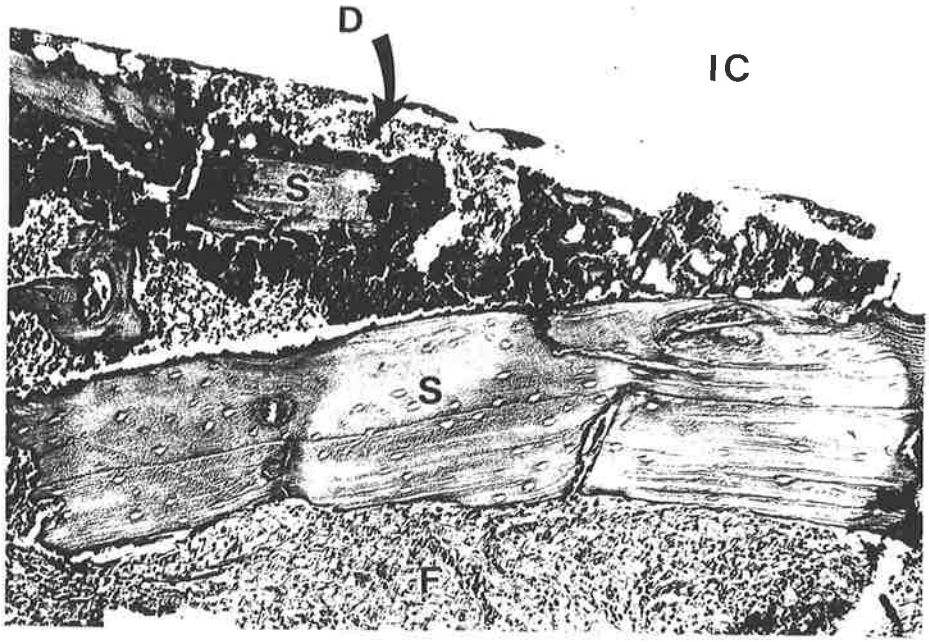
NOTE: throughout this thesis, the following conventions are used:

1. H&E = haematoxylin and eosin
2. Magnification refers to the original microscopic magnification, being the product of the objective and the photoeyepiece.
3. C = collagen
   CB = cortical bone
   F = fibrous connective tissue
   IC = implant cavity/implant
   NB = new bone matrix

Fig. 4.24 **COPPER** **4 WEEKS**

Photomicrograph of Zone 2, showing soft tissue debris (D) and peripheral fibrous tissue.

H&E
Original magnification x33


D
IC
S
S
F

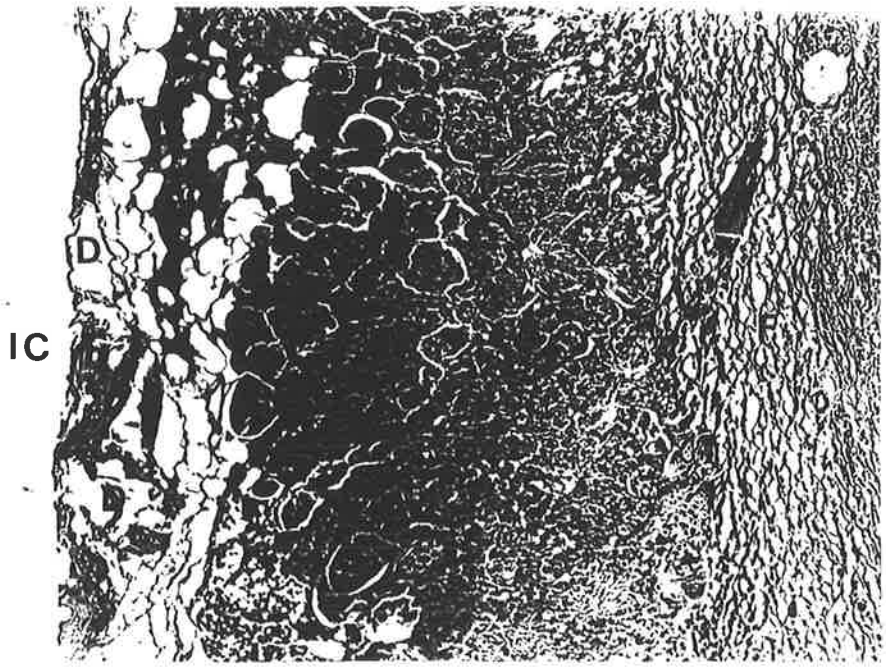

IC
D
D
F

Fig. 4.25 **COPPER** **4 WEEKS**

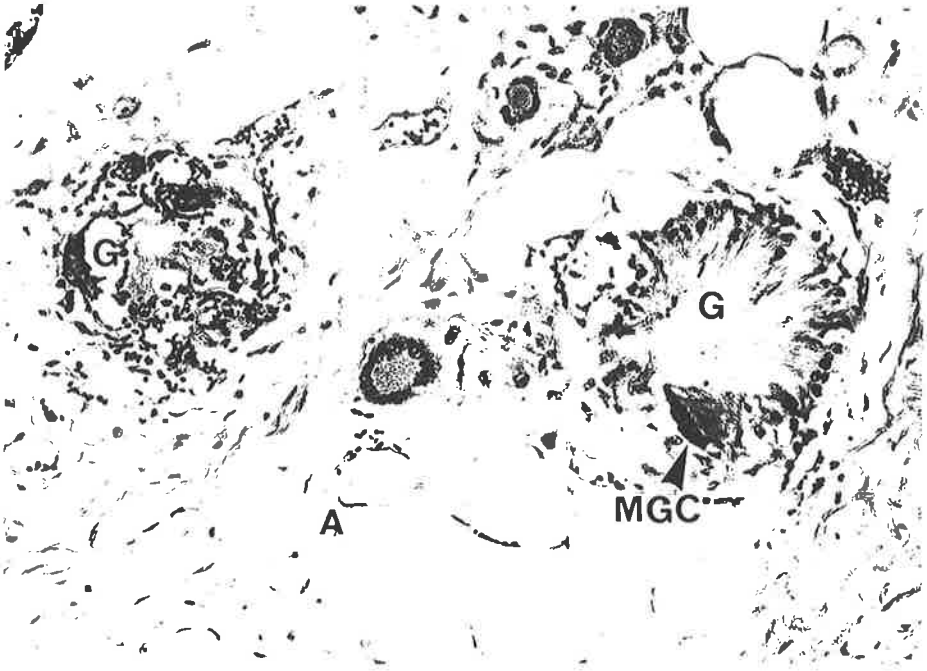
Photomicrograph of part of Zone 2 adjacent to the copper implant, demonstrating the presence of granulomas (G) of varying sizes, surrounded by fibro-adipose tissue (A). The appearance of the granulomas shown here is representative of those seen around all other implants in the same animal. Note the multi-nucleated giant cells (MCG).

H&E
Original magnification x33

Fig. 4.26 **COPPER** **4 WEEKS**

Higher power view of granuloma shown in Fig. 4.25, demonstrating focal aggregates of histiocytes (H) and a fibrillar pattern of amorphous material (A). No identifiable foreign body can be seen.

H&E
Original magnification x66


G
G
MGC
A

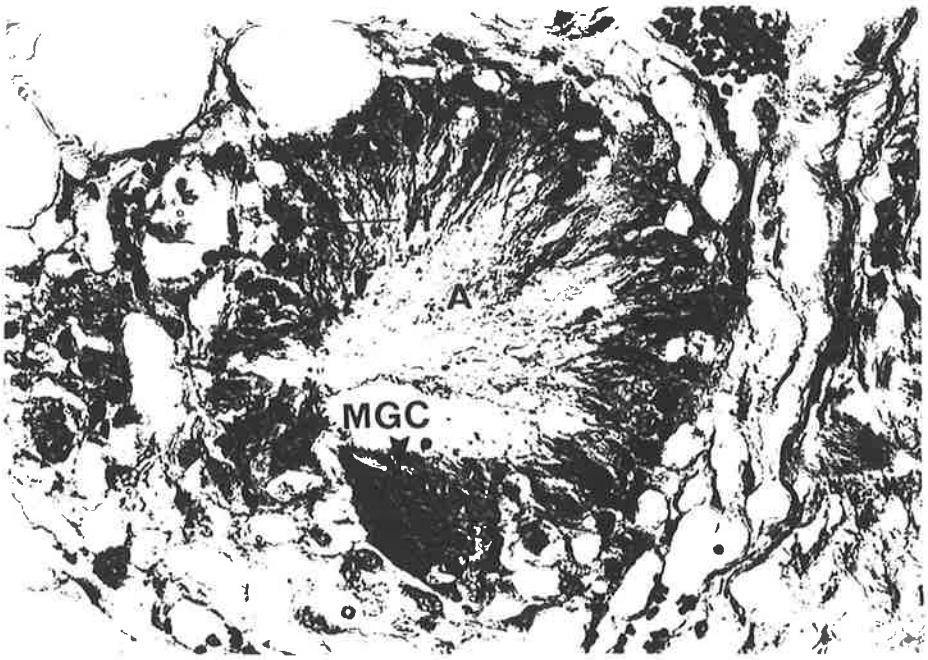

A
MGC

Fig. 4.27 **DENTOZYL®** **4 WEEKS**

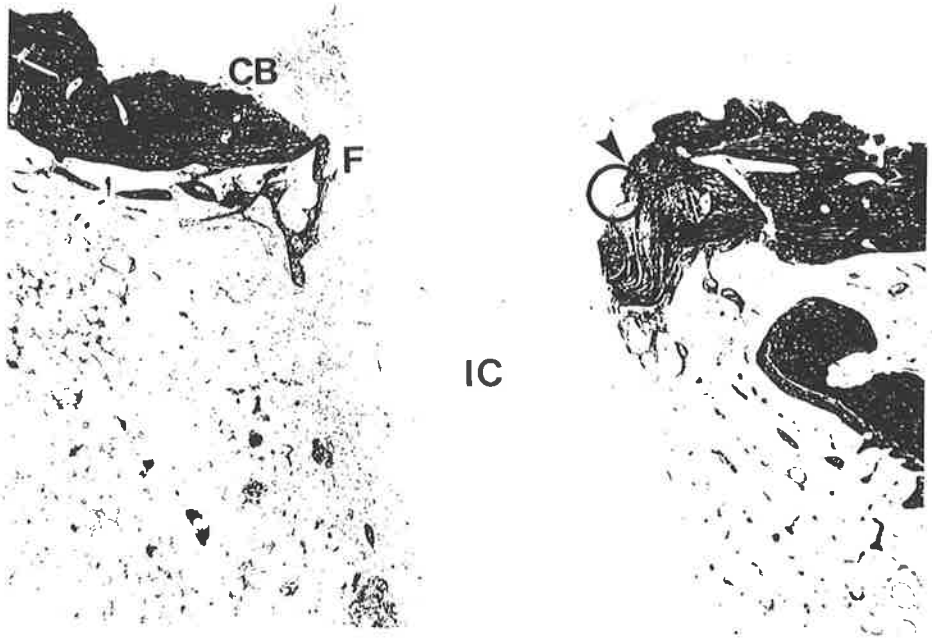
Low power photomicrograph of Zone 1 and part of Zone 2, demonstrating the presence of a prominent layer of fibrous tissue between the cortical bone and the implant cavity on one side. On the other side, a focal area of bone resorption (arrowed) can be seen at the periosteal surface, covered with fibrous tissue. On this side, bone appears to abut the implant space.

Trichrome
Original magnification x6.6

Fig. 4.28 **DENTOZYL®** **4 WEEKS**

Higher power view of the area circled in Fig. 4.27. Osteoclasts (O) can be seen on the surface of the cortical bone.

Trichrome
Original magnification x132


CB
F
IC


O

Fig. 4.29 **DENTOZYL®** **4 WEEKS**

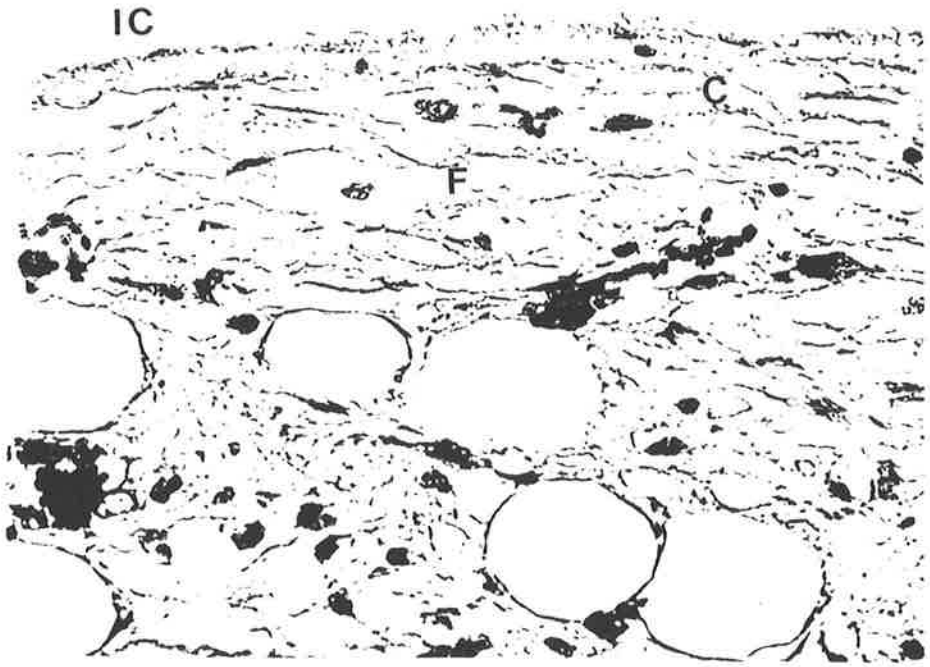
High power view of the tissue surrounding the implant cavity in Zone 2. A diffuse fibrous tissue layer is present with collagen fibres arranged parallel to the implant space.

H&E
Original magnification x132

Fig. 4.30 **SILVER** **4 WEEKS**

Low power photomicrograph of tissue in Zones 1 and 2 surrounding a silver implant cavity. Variations can be seen at each side in Zone 1; on one side the cortical bone appears to abut directly the cavity, whereas a thick fibrous layer is interposed between the bone and cavity on the opposite side.

Trichrome
Original magnification x6.6


IC
C
F

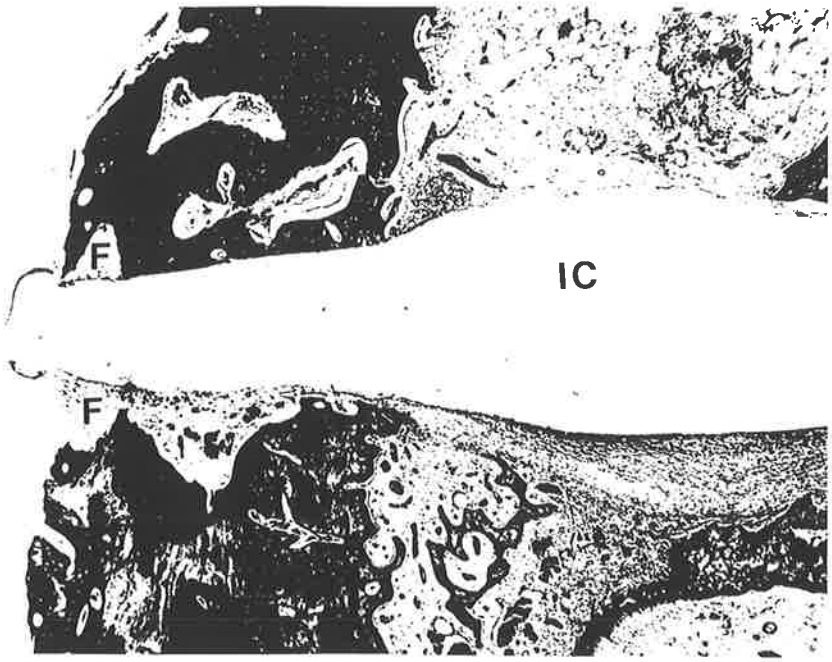

F
IC
F

Fig 4.31 **SILVER** **4 WEEKS**

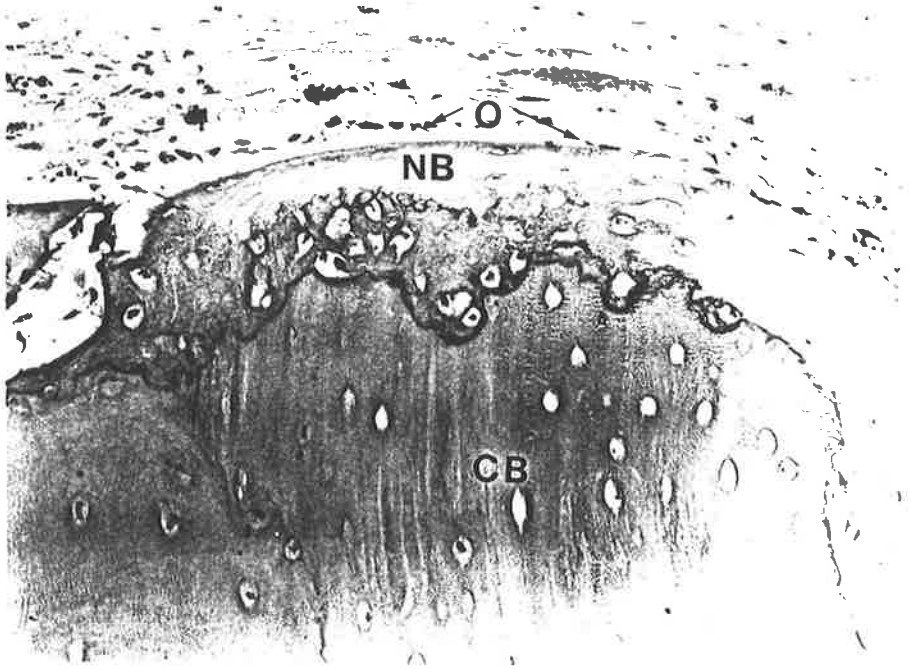
Higher power view of a cortical bone/ fibrous tissue interface in Zone 1. New bone deposition (NB) is seen on the surface of the cortical bone.
The margin of the cortical bone is smooth and regular, with osteoblasts (O) along the surface. Within the bone, osteocytes in Howship's lacunae can be seen.

H&E
Original magnification x66

Fig. 4.32 **SILVER** **4 WEEKS**

Photomicrograph illustrating the cortical bone surface in Zone 1 in an area devoid of fibrous tissue. Focal indentations containing fibrous tissue are noticed; the remaining bone surface is smooth.
There is no evidence of new bone formation.

H&E
Original magnification x33


O
NB
CB

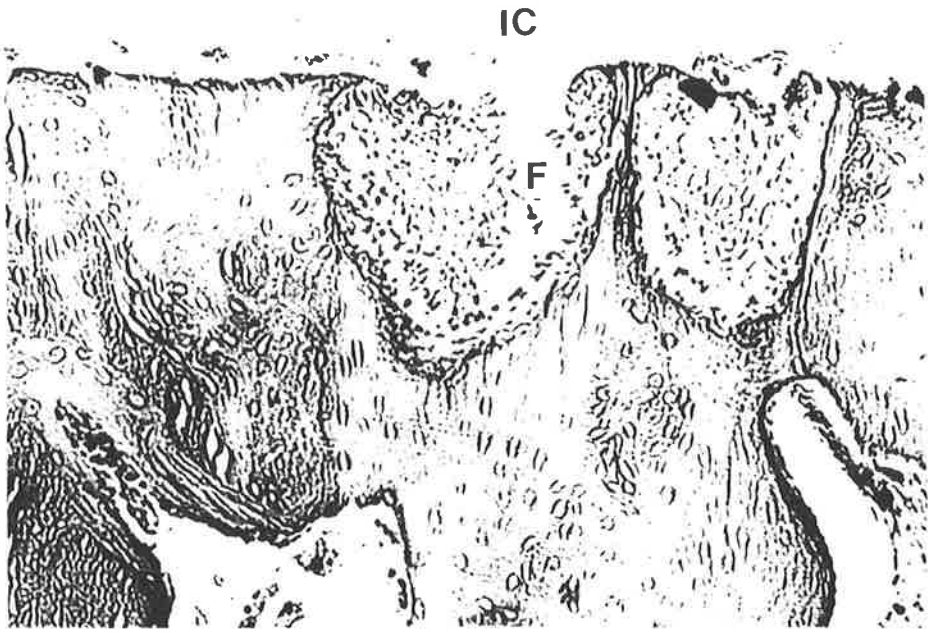

IC
F

Fig. 4.33 **SILVER** **4 WEEKS**

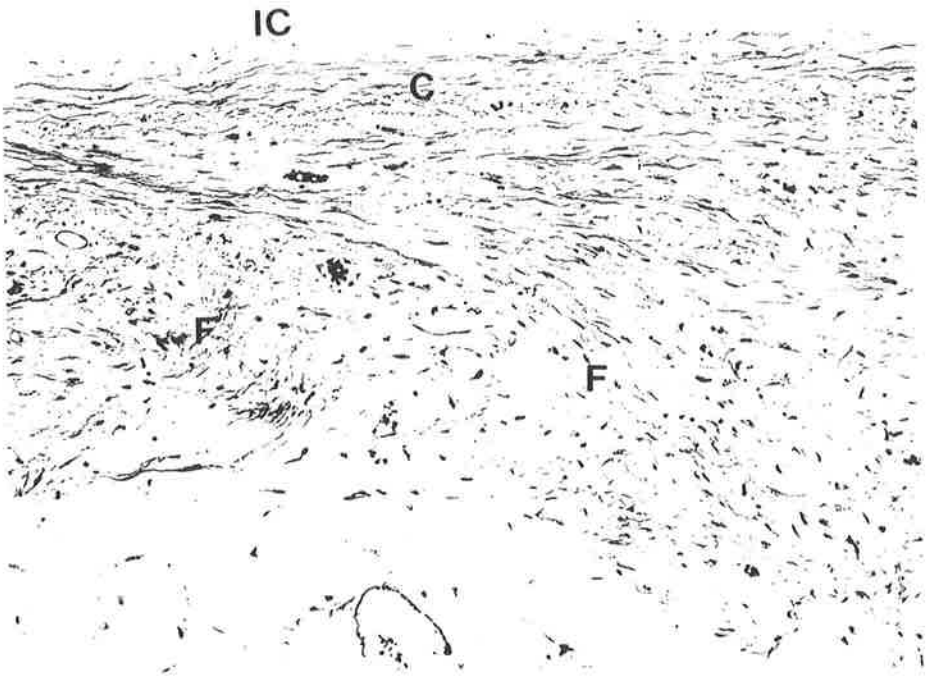
High power photomicrograph of the fibrous tissue surrounding the implant cavity in Zone 2. Densely packed collagen fibres are aligned near the cavity. Peripheral to the fibrous capsule the medullary contents are mainly adipose tissue.

H&E
Original magnification x66?

Fig. 4.34 **SILVER** **4 WEEKS**

Photomicrograph demonstrating the implant space which had penetrated a tooth root. A thin layer of amorphous debris is seen at the interface (arrowed). Cellular mineralised matrix is seen directly abutting the implant space. Osteoid-like material (O) is seen on dentine chips (D).

H&E
Original magnification x66


IC
C
F
F

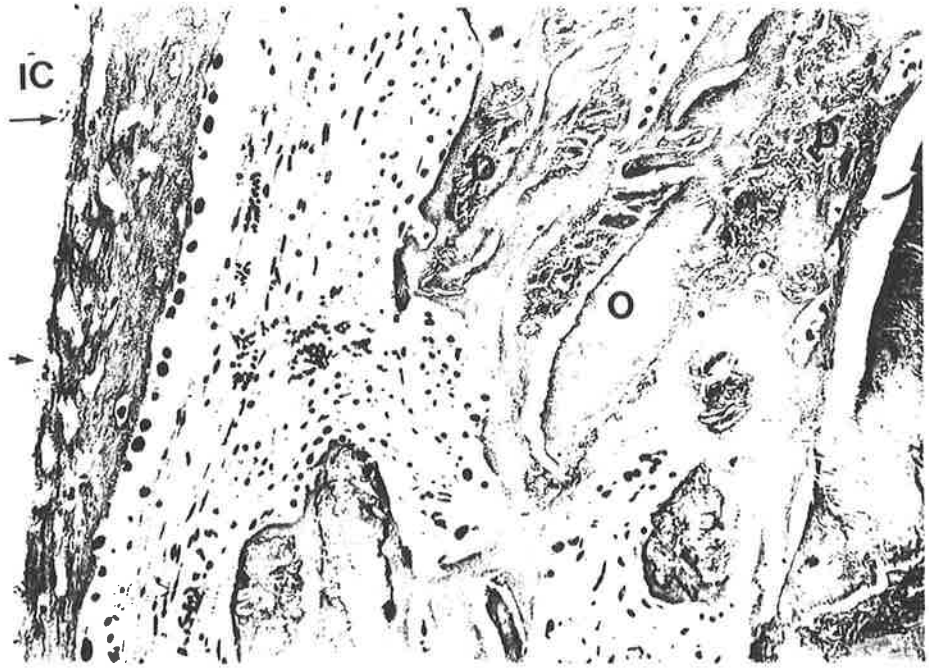

IC
D
D
O

Fig. 4.35 **PLATINUM** **4 WEEKS**

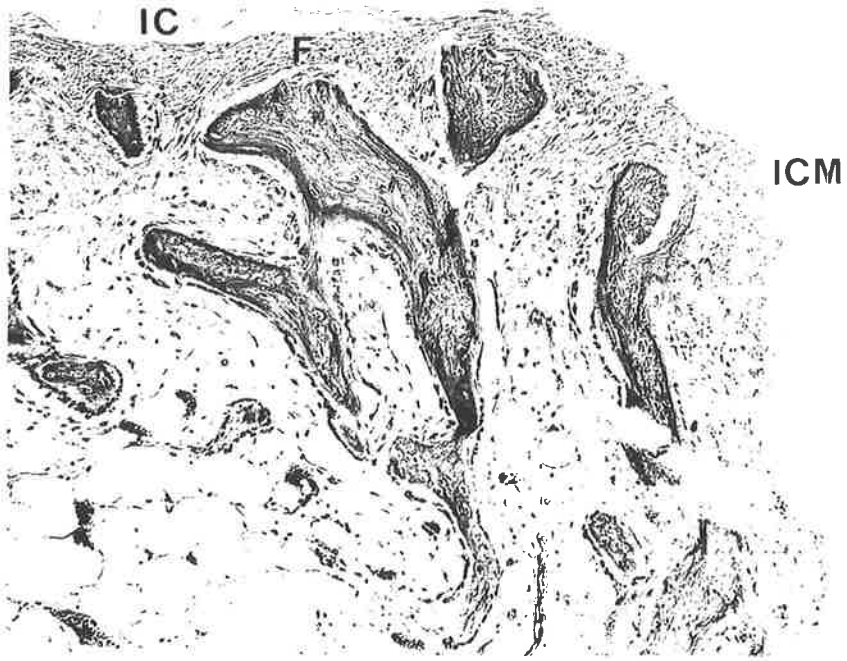
Low power photomicrograph of Zone 1, which consists of trabeculae rather than a thick identifiable layer. A thin layer of fibrous connective tissue is visible between the trabeculae and implant cavity, and also along the inferior cortical margin (ICM).

H&E
Original magnification x33

Fig. 4.36 **PLATINUM** **4 WEEKS**

Photomicrograph of the bone:implant cavity interface in Zone 1 in an area devoid of fibrous tissue. Osteoblasts (O) are seen on the surface of the cortical bone.

H&E
Original magnification x33


IC
F
ICM

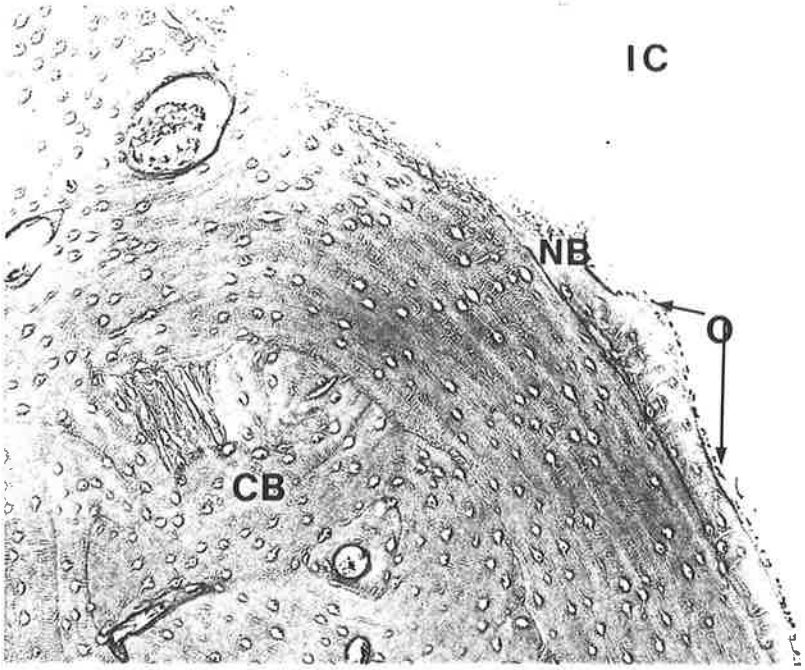

IC
NB
O
CB

Fig. 4.37 **PLATINUM** **4 WEEKS**

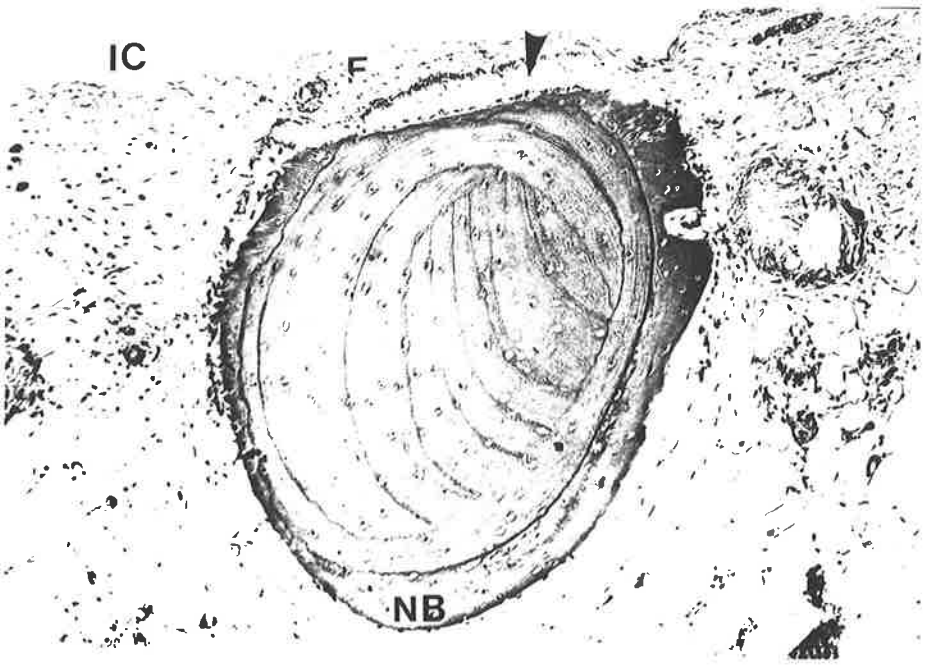
High power view of a trabecula within Zone 2. Note the new bone matrix formation around pre-existing bone. A relatively prominent fibrous tissue layer is seen between the bone and the implant space. An artifactual splitting (arrowed) between the bone and soft tissue is seen.

H&E
Original magnification x66

Fig. 4.38 **PLATINUM** **4 WEEKS**

Trabecula of bone seen within Zone 2 of the same implant as that in Fig. 4.37. Note the new bone matrix formation (NB), and its proximity to the implant cavity in places.

H&E
Original magnification x66


IC
F
NB

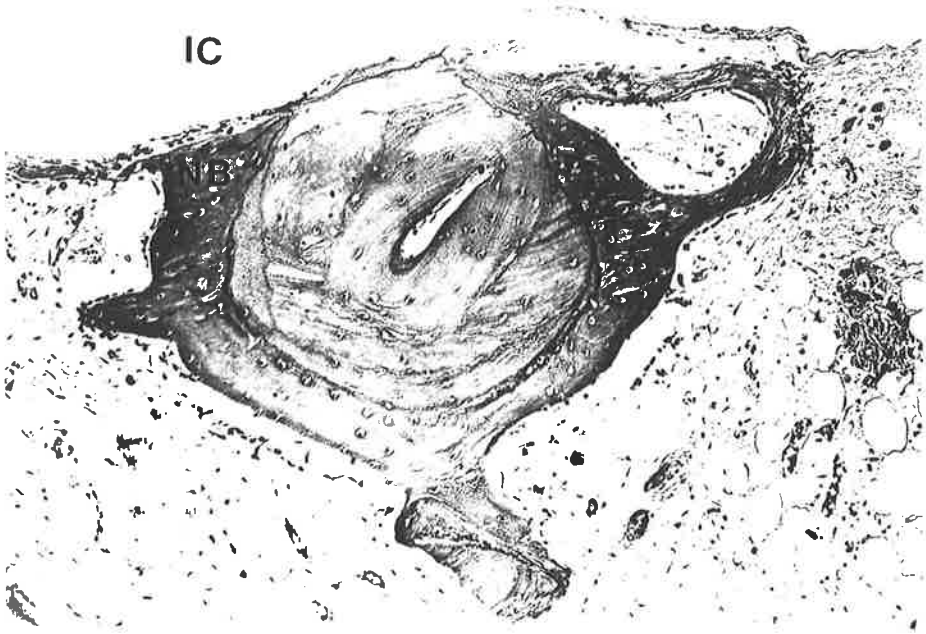

IC

Fig. 4.39 **PALLADIUM** **4 WEEKS**

Photomicrograph of bone trabecula (T) adjacent to the implant cavity. New bone deposition is seen, with osteoblasts (O) along the surface of the trabecula.

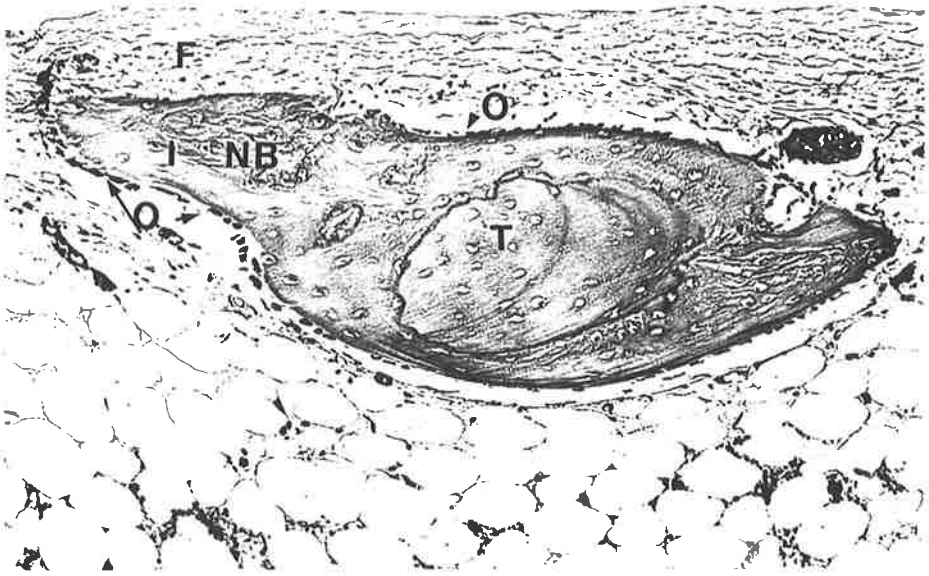
H&E
Original magnification x33

Fig. 4.40 **PALLADIUM** **4 WEEKS**

Low power photomicrograph showing the implant cavity penetrating a tooth. Dentine is visible on either side of the cavity and dentine spicules are present at the apex and lateral margins of the cavity.

H&E
Original magnification x3.3

IC



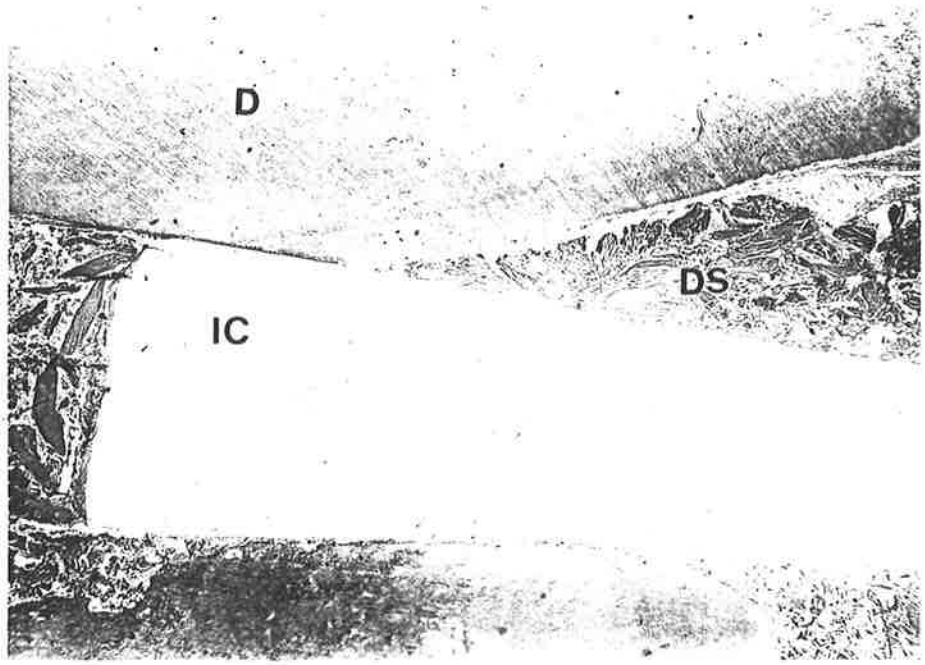


Fig. 4.41 **PALLADIUM** **4 WEEKS**

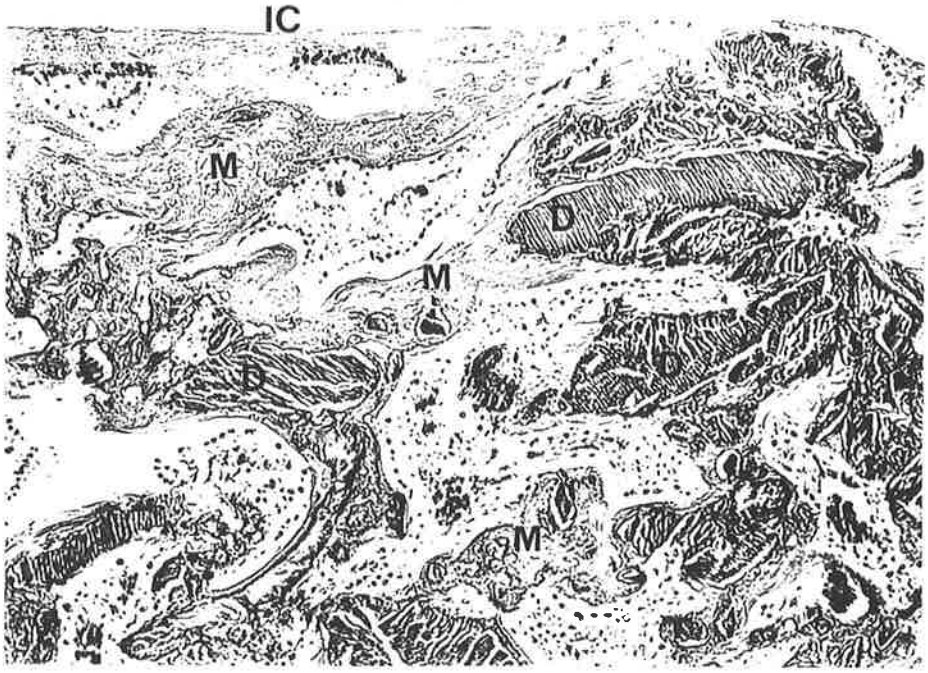
Higher power view of dentine spicules (D) and mineralising matrix (M) along the lateral margin of the implant cavity.

H&E
Original magnification x33

Fig. 4.42 **GOLD ALLOY** **4 WEEKS**

Low power photomicrograph of Zone 1. Focal areas of fibrous tissue (F) can be seen, as can small areas where cortical bone appears to abut the implant cavity. A layer of tissue at the cortical margin can be seen; this had partially covered the implant *in vivo*.

H&E
Original magnification x6.6


IC
M
D
M
D
M

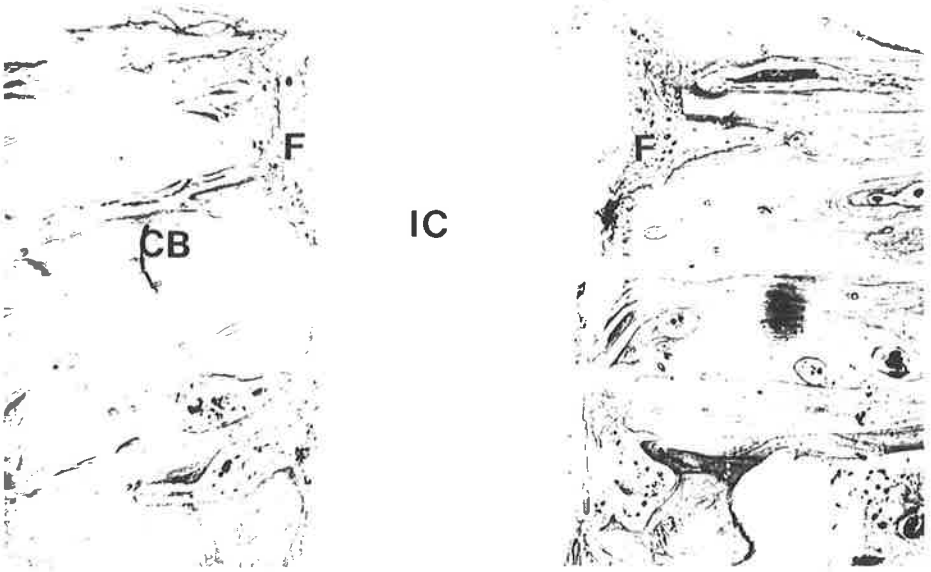

F
CB
IC
F

Fig. 4.43 **GOLD ALLOY** **4 WEEKS**

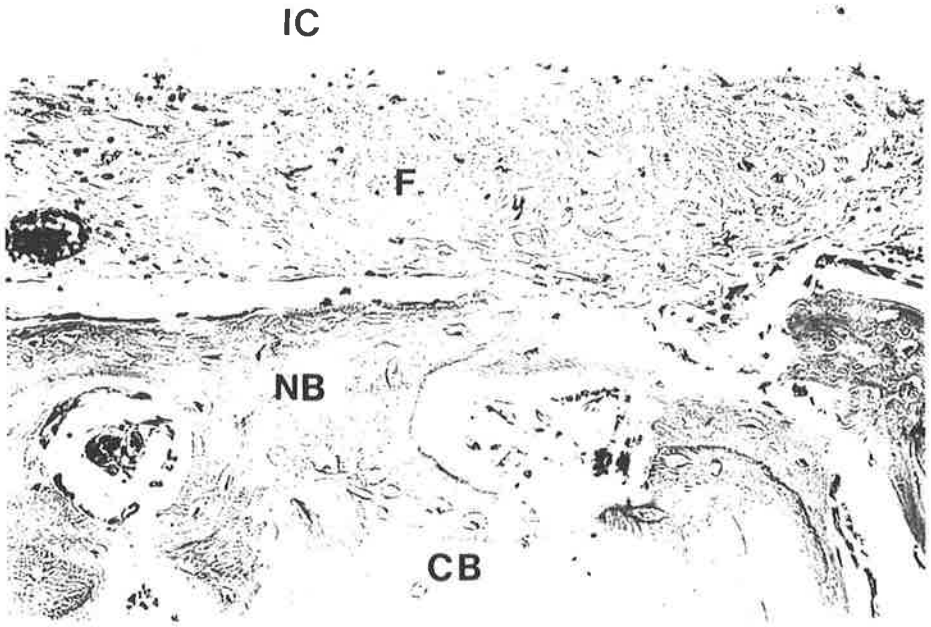
Higher power view of the cortical bone surface peripheral to the fibrous tissue. The collagen fibres are irregularly orientated. New bone formation can be seen in the peripheral cortical bone. Osteocytes are present within lacunae and osteoblasts can be seen along the surface of the bone.

H&E
Original magnification x66

Fig. 4.44 **GOLD ALLOY** **4 WEEKS**

Photomicrograph of loosely arranged fibrous tissue adjacent to the implant cavity in Zone 2. A condensed fibrous zone is present at the surface and the capsule blends with the medullary contents. Metallic debris (arrowed) is present.

H&E
Original magnification x132


IC
F
NB
CB

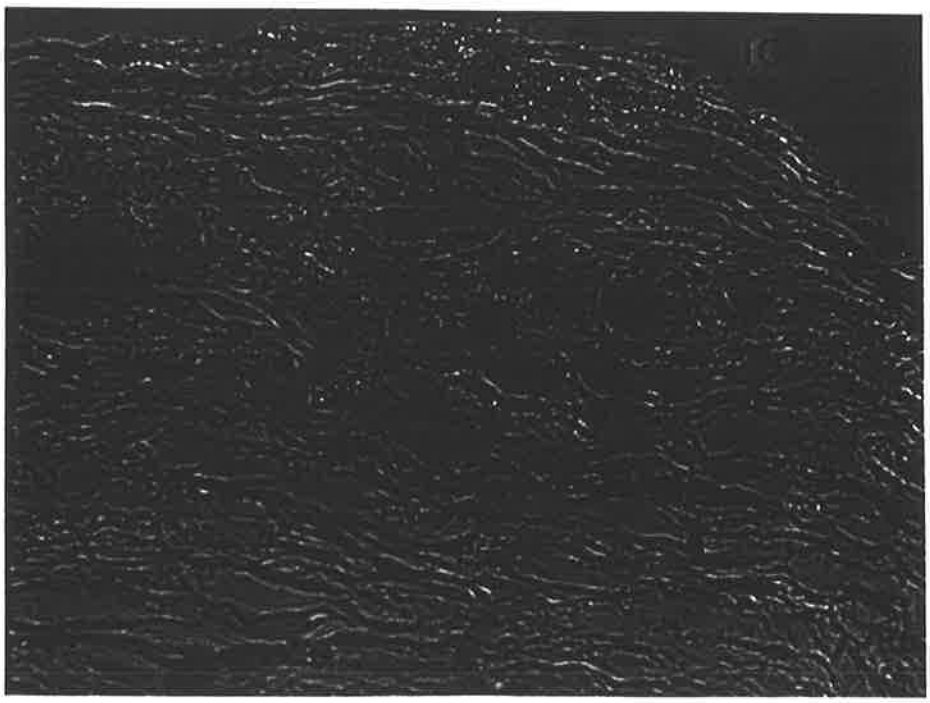


Fig. 4.45 **GOLD** **4 WEEKS**

Photomicrograph of cortical bone appearing to abut the implant cavity directly. No evidence of bony remodelling is seen.

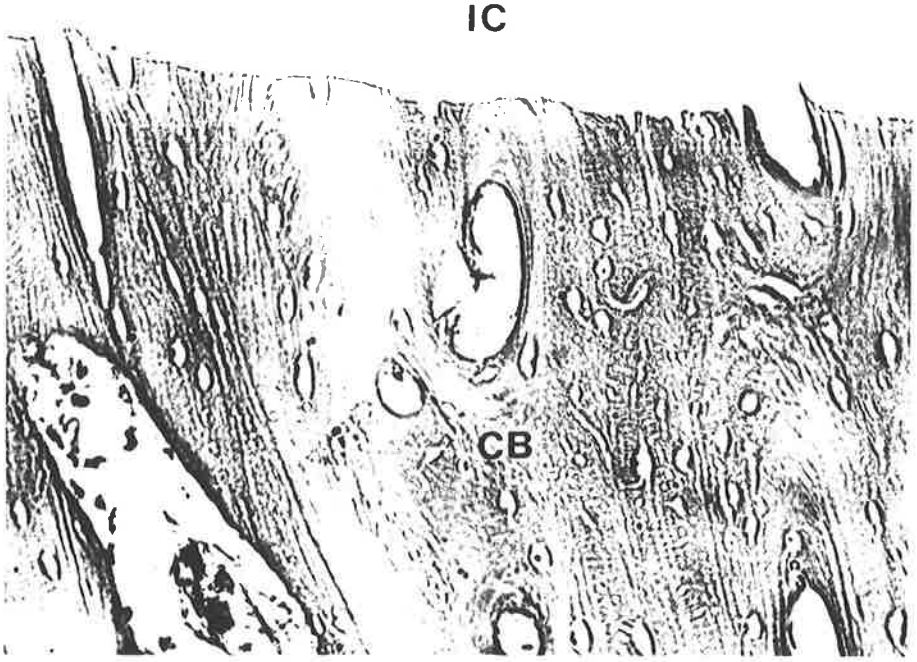
Trichrome
Original magnification x33

Fig. 4.46 **GOLD** **4 WEEKS**

Photomicrograph of part of Zone 2. An ill-defined zone of fibrous tissue is present immediately adjacent to the implant cavity. The peripheral medullary contents are mainly adipose tissue (A).
Note the granuloma (G) and area of extravasated erythrocytes (E) in this section.

H&E
Original magnification x33.

IC



IC

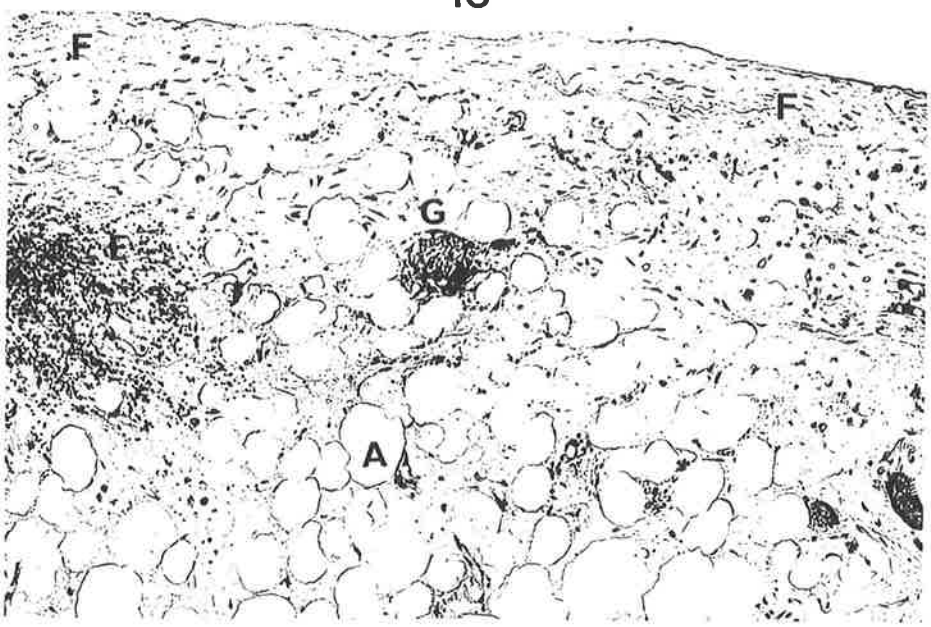


Fig. 4.47 **COPPER** **13 WEEKS**

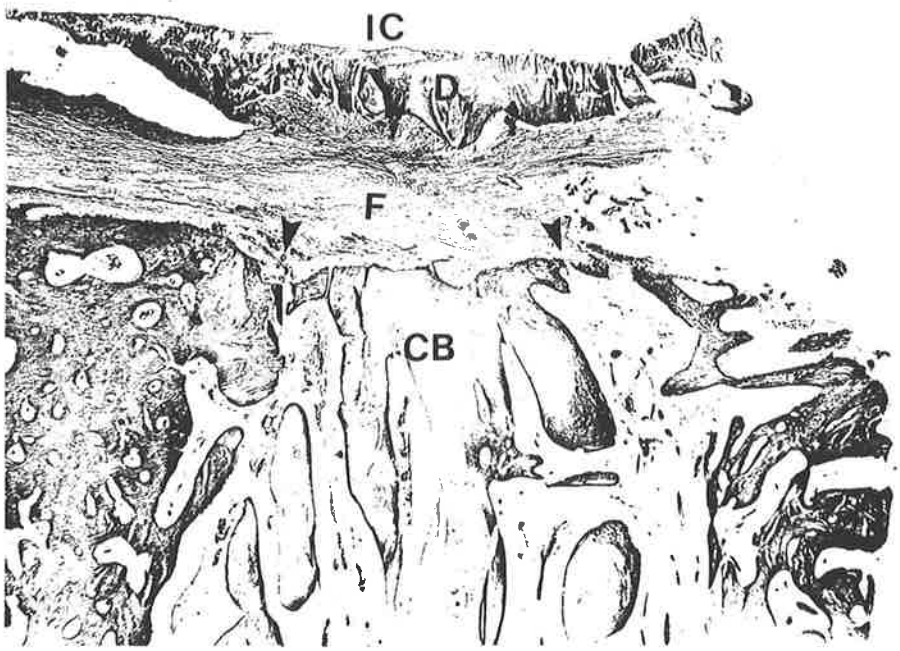
Necrotic debris (D) is seen adjacent to the implant cavity, peripheral to which is an irregular band of fibrous tissue, with collagen fibres aligned parallel to the cavity. The cortical bone has rough irregular margins, in places infiltrated by fibrous tissue (arrowed).
The area of apparent tissue loss at the margin of the implant cavity is artifactual.

H&E
Original magnification x6.6

Fig. 4.48 **DENTOZYL®** **13 WEEKS**

Photomicrograph of tissue adjacent to the implant cavity (IC) in Zone 1. A thin layer of fibrous tissue (F) containing metallic debris (M) and extravasated erythrocytes (E) can be seen. New bone matrix formation is present at the inferior cortical margin.

H&E
Original magnification x33


IC
D
F
CB

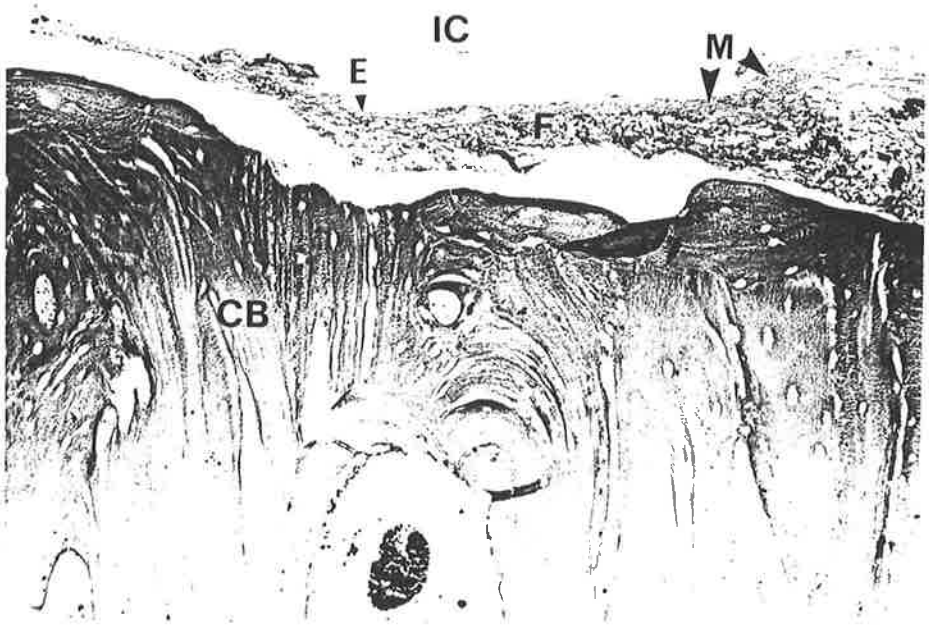

IC
E
M
F
CB

Fig. 4.49 **DENTOZYL®** **13 WEEKS**

Photomicrograph showing pre-existing cortical bone (CB) and new bone formation (NB) in Zone 1.

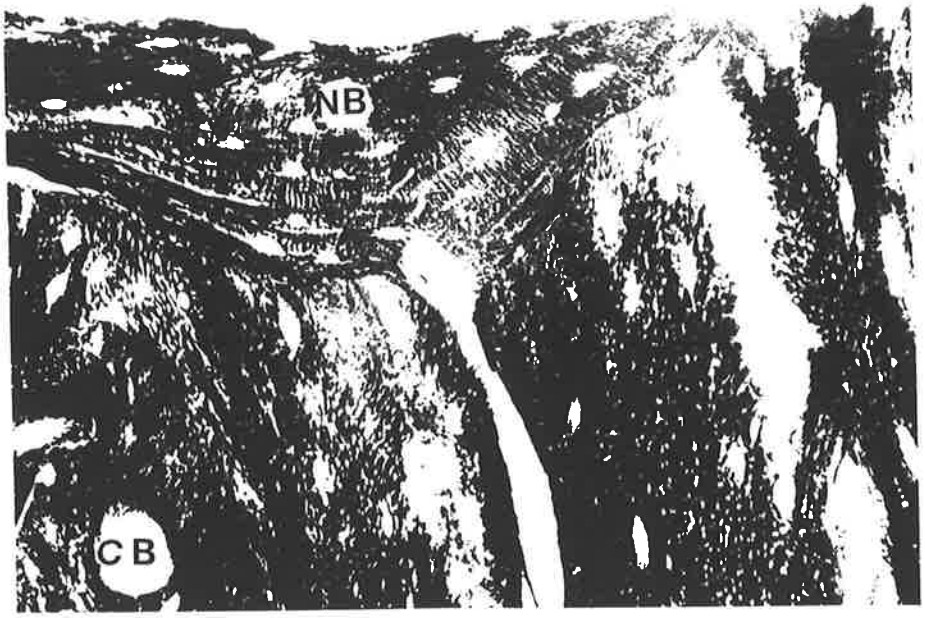
Trichrome
Original magnification x66

Fig. 4.50 **DENTOZYL®** **13 WEEKS**

Low power photomicrograph of new bone over the cortical end of the implant cavity (IC). Lamellae are parallel to the inferior cortical margin (ICM).

H&E
Original magnification x33

IC



IC

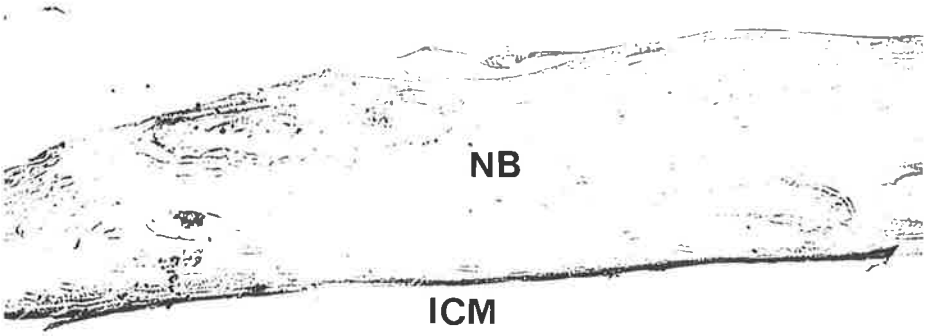


Fig. 4.51 **DENTOZYL®** **13 WEEKS**

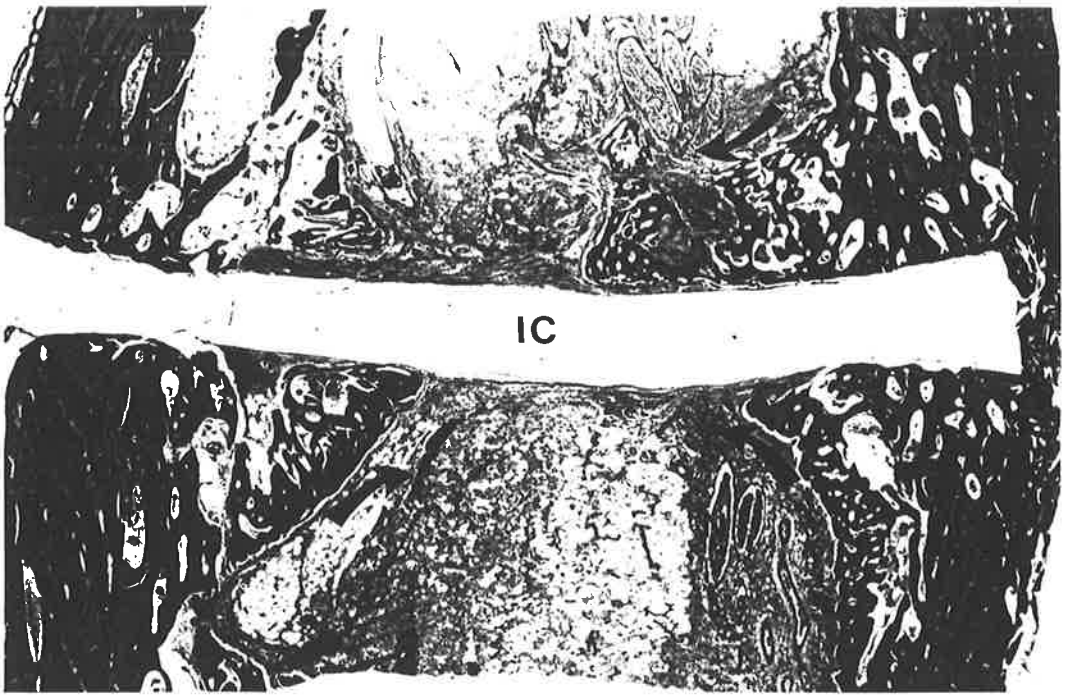
Low power photomicrograph showing apparent ingrowth of cortical bone in a triangular fashion (arrowed) from the lingual and inferior cortices towards the centre of the medulla.
N = inferior dental nerve.

Trichrome
Original magnification x3.3

Fig. 4.52 **DENTOZYL®** **13 WEEKS**

Photomicrograph of bony ingrowth (arrowed) from the lingual cortical plate towards the medulla. A thin layer of fibrous tissue in places separates the bone from the implant cavity.

Trichrome
Original magnification x6.6


IC

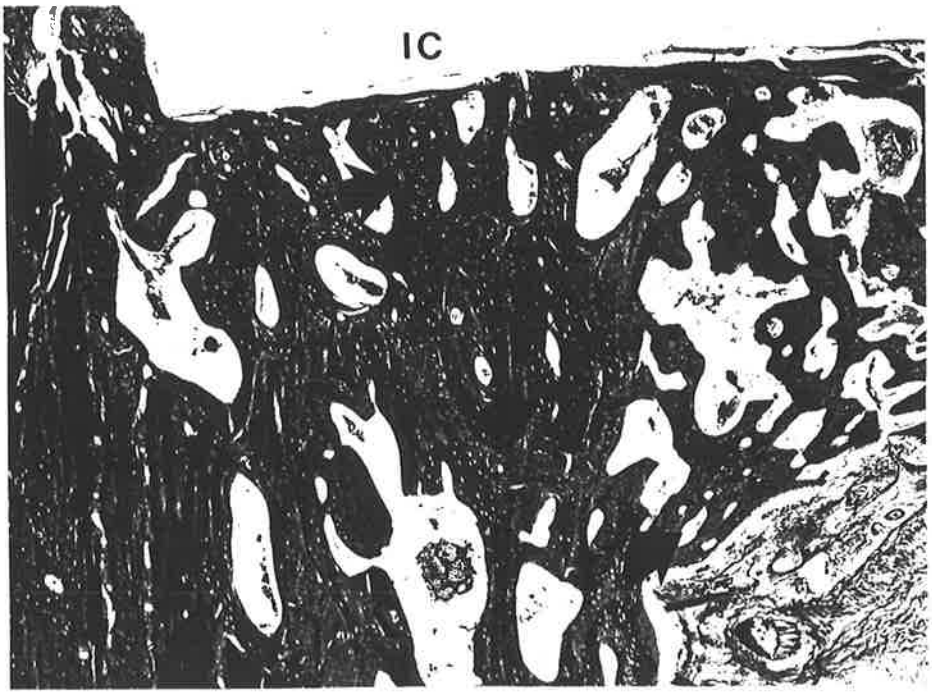

IC

Fig. 4.53 **SILVER** **13 WEEKS**

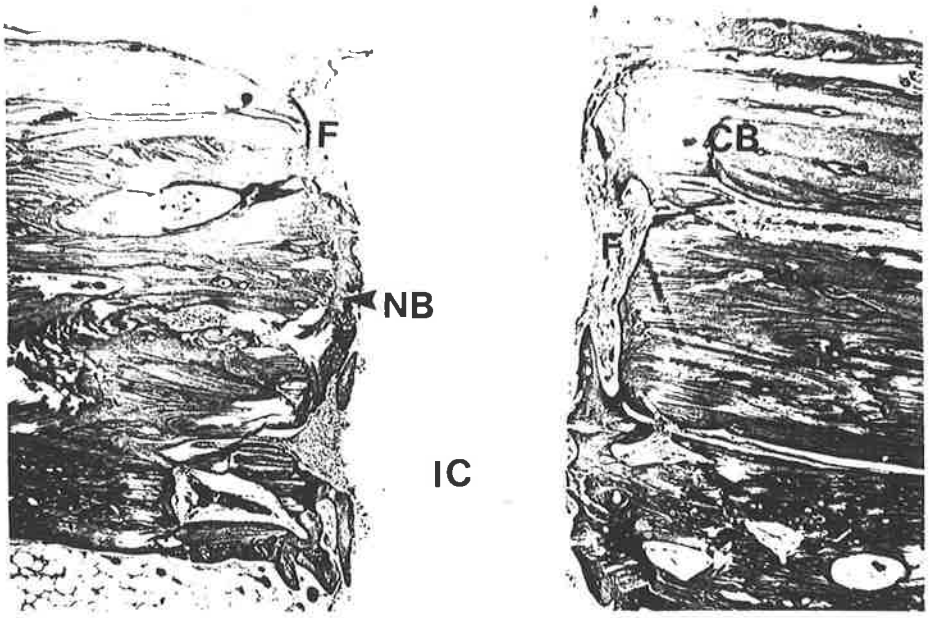
Low power photomicrograph of Zone 1. Areas of fibrous tissue of varying thickness can be seen adjacent to the implant space.

H&E
Original magnification x6.6

Fig. 4.54 **SILVER** **13 WEEKS**

Higher power view of cortical bone and nutrient channel. Note the area of altered staining adjacent to the implant cavity. Metallic debris (D) is present within the nutrient channel. Amorphous debris is present at the interface (arrowed).

H&E
Original magnification x66


F
NB
IC
CB
F

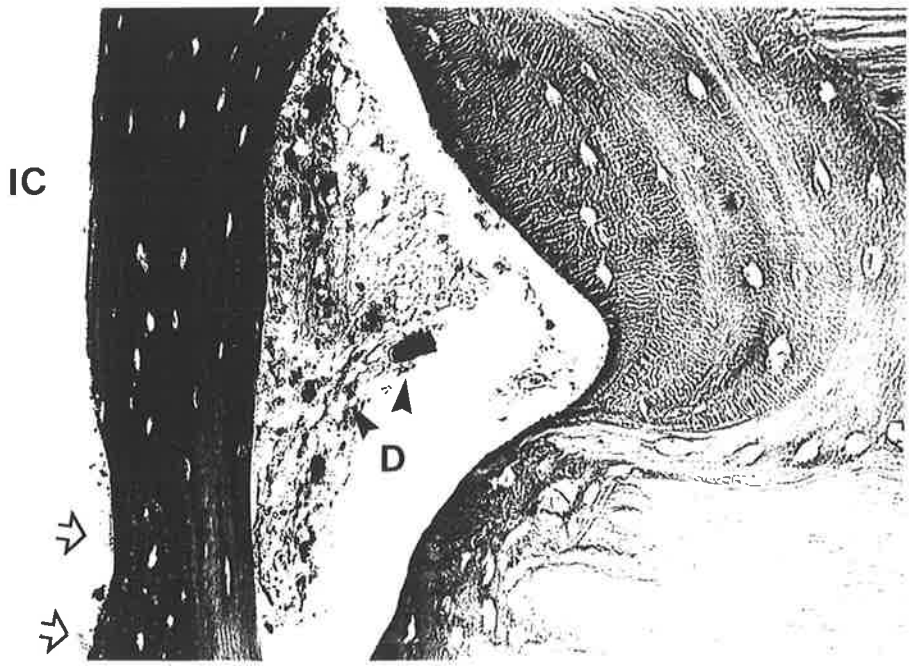

IC
D

Fig. 4.55 **PLATINUM** **13 WEEKS**

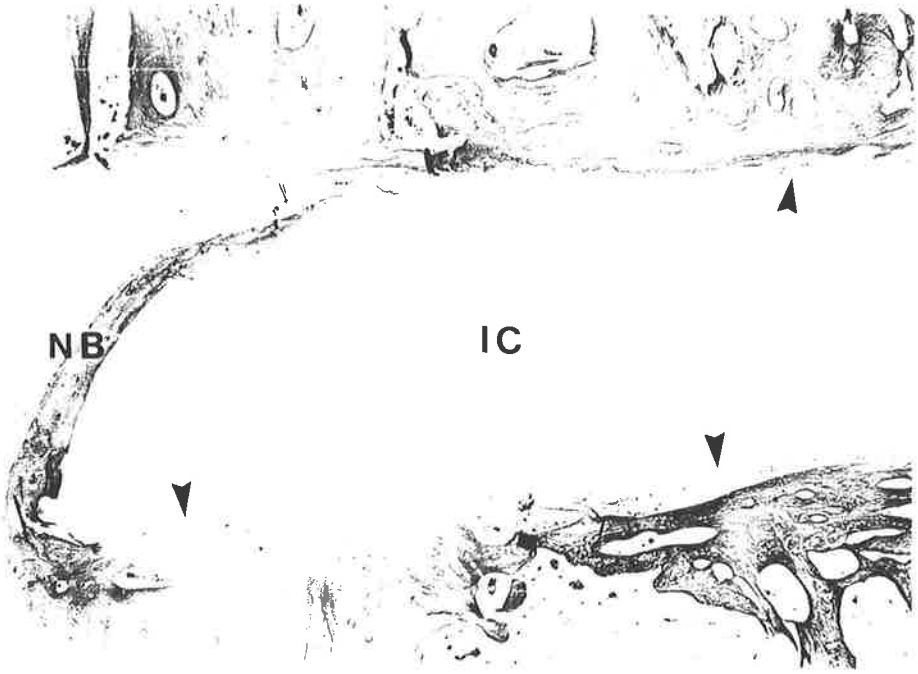
Photomicrograph of Zone 1 showing isolated areas of fibrous tissue (arrowed) adjacent to the implant cavity. An area of new bone formation can be seen at the inferior cortical margin. This has been cut to facilitate recovery of the implant.

H&E
Original magnification x6.6

'Fig. 4.56 **PALLADIUM** **13 WEEKS**

Photomicrograph of the lingual cortical plate adjacent to the implant cavity. Note the new bone at the interface.
D = metallic debris at interface.

H&E
Original magnification x33


NB
IC

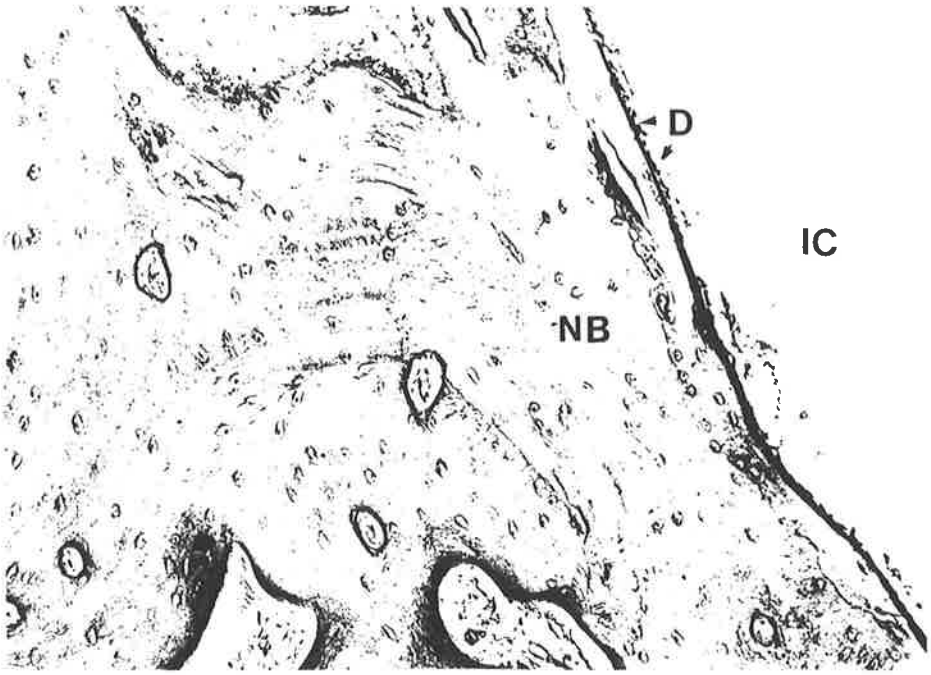

D
IC
NB

Fig. 4.57 **GOLD ALLOY** **13 WEEKS**

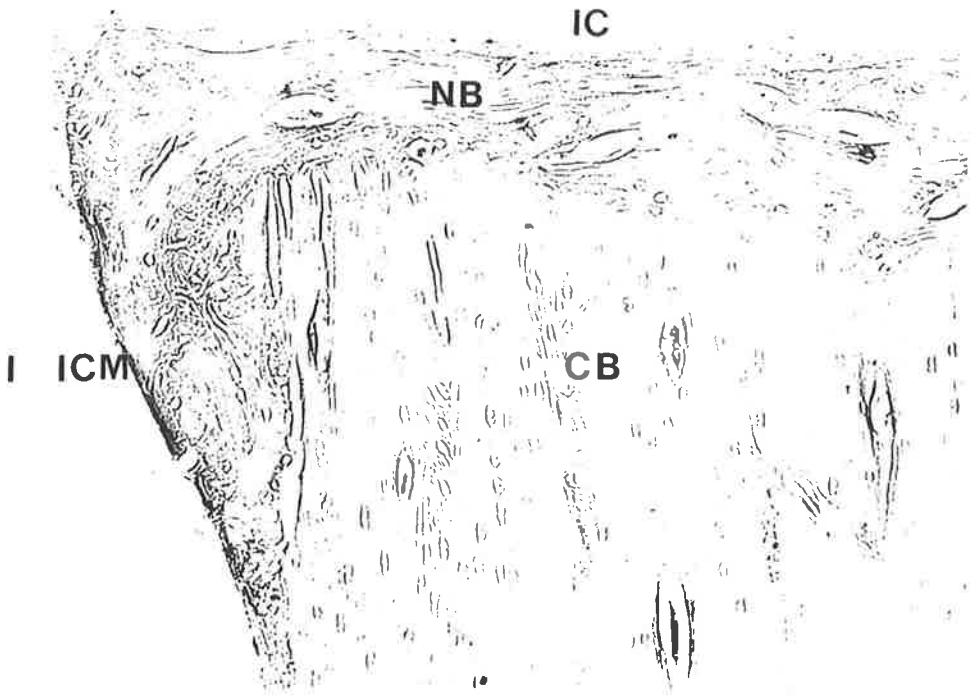
Photomicrograph of Zone 1. Remodelling of the cortical bone (NB) can be seen adjacent to the implant cavity. At the inferior cortical margin (ICM), new bone is also seen; this corresponds with a cuff of tissue seen around the neck of the implant on gross examination. A very thin layer of fibrous tissue and amorphous debris separates the bone from the implant cavity.

H&E
Original magnification x33

Fig. 4.58 **GOLD ALLOY** **13 WEEKS**

Low power photomicrograph of thick fibrous tissue adjacent to the implant cavity in Zone 1. The peripheral cortical bone shows evidence of bony remodelling (arrowed).

H&E
Original magnification x33


IC
NB
I
ICM
CB

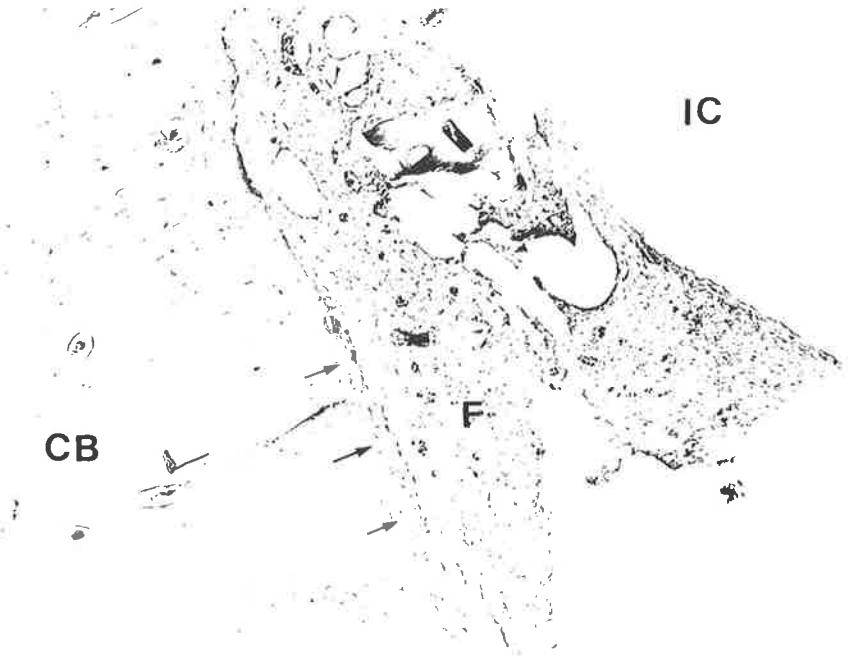

IC
F
CB

Fig. 4.59 **GOLD ALLOY** **13 WEEKS**

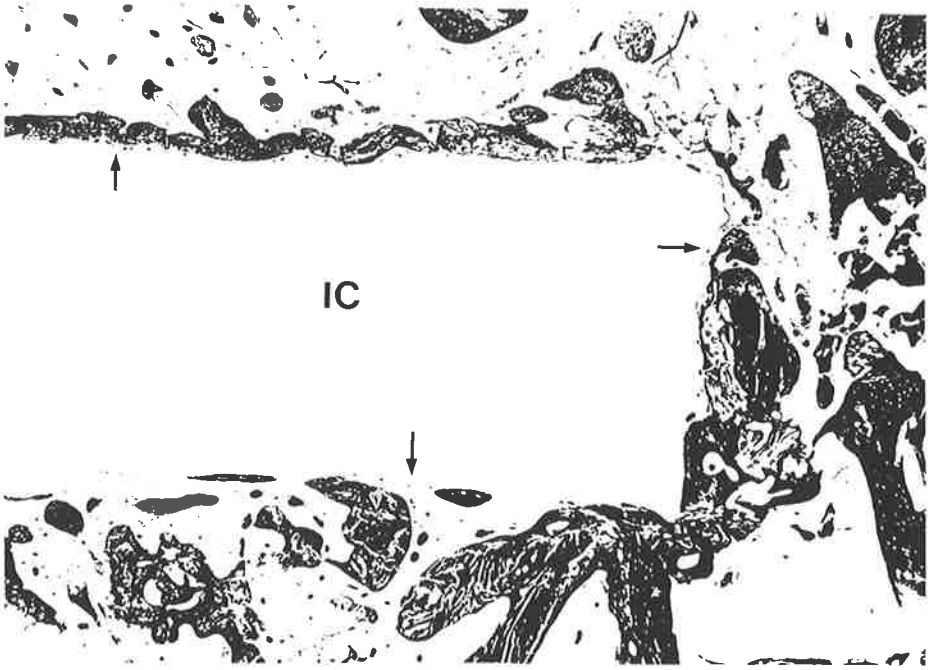
Low power photomicrograph showing trabeculae surrounding and abutting the implant cavity in Zone 2. A very thin fibrous layer can be seen in places (arrowed).

Trichrome
Original magnification x6.6

Fig. 4.60 **GOLD** **13 WEEKS**

Low power photomicrograph demonstrating a thick capsule of fibrous tissue (F) surrounding the implant cavity in Zone 1. Note the different appearances of the margins of the cortical bone facing the implant cavity. On one side, evidence of bony remodelling is seen (arrowed). On the opposite side there is no evidence of bony remodelling.

H&E
Original magnification x6.6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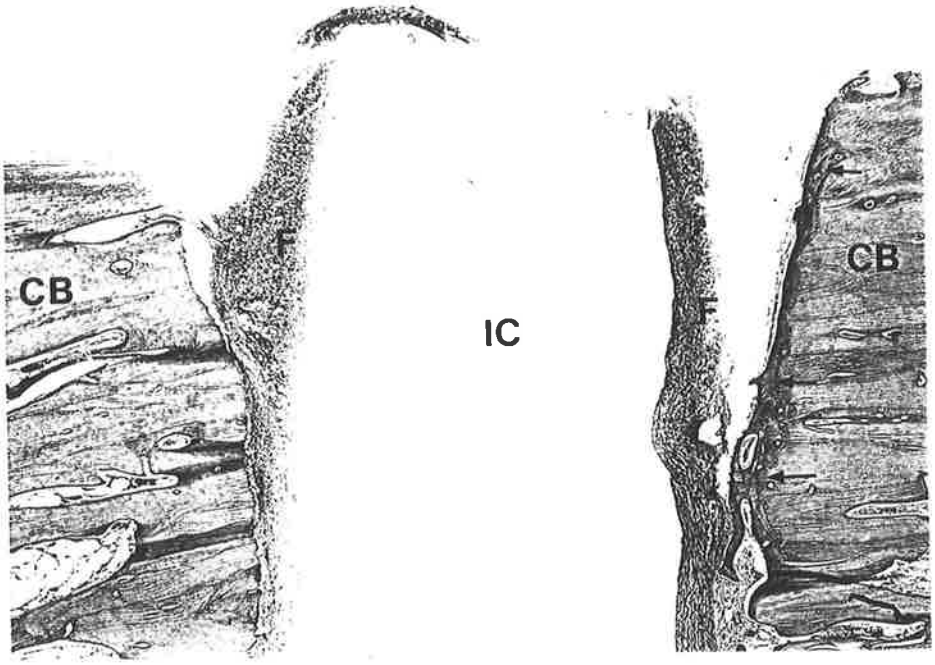
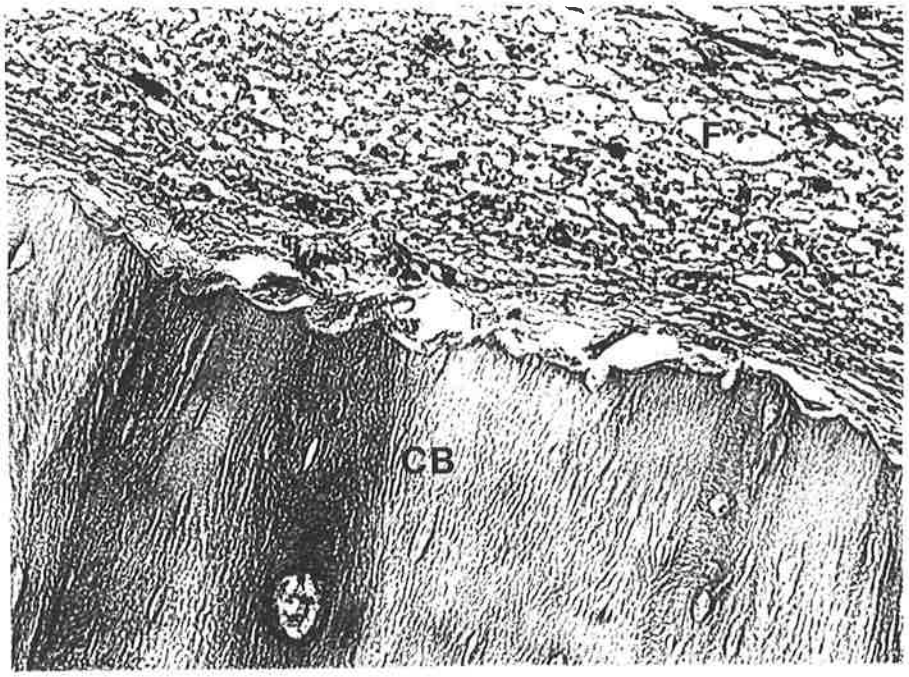

CB
IC
CB

Fig. 4.61 **GOLD** **13 WEEKS**

Higher power view of Zone 1. There is no evidence of bony remodelling on the surface of the bone immediately adjacent to the fibrous tissue.

Trichrome
Original magnification x66


F
CB

4.4 OPTICAL MICROSCOPY - UNDECALCIFIED MATERIAL

In general, examination of the undecalcified material in both experimental groups revealed responses around the metal implants similar to those seen in the decalcified material.

a) AFTER FOUR WEEKS

Copper

Within Zone 1 of all sections examined, the interface between the implant and surrounding bone was characterised by gross tissue destruction, with a layer of fibrous tissue interposed between the cortical bone and necrotic debris. The cortical facing the implant bone demonstrated a smooth outline. On the inferior cortical margin, a proliferative connective tissue reaction was noticed, with a focal area of periosteal new bone formation.

Examination of Zone 2 demonstrated continuation of the necrotic layer and fibrous tissue from Zone 1, extending around the implant.

Dentozyl®

Within Zone 1 of sections from two specimens examined, focal areas of fibrous tissue were noticed interposed between the implant and surrounding cortical bone. In areas devoid of fibrous tissue, immature bone formation was noticed close to the interface with the implant.

Macroscopic examination of the other specimen had shown that the implant had been covered by tissue. Microscopic examination of this specimen demonstrated a layer of fibrous tissue surrounding the implant in Zone 1, and extending over the inferior end of the implant. The cortical bone peripheral to this showed an irregular margin, with no evidence of bony remodelling. A layer of

periosteal new bone was present at the inferior cortical margin, and over the implant (Fig. 4.62).

Zone 2 in one specimen demonstrated a thin layer of fibrous tissue surrounding the implant. Peripheral to the fibrous tissue were normal medullary contents, mainly adipose tissue and the mandibular neuro-vascular bundle.

In the other two specimens, the implants were seen to have penetrated the pulps of the teeth. Mineralisation around some of the dentine chips was apparent, some of which was in very close proximity to the implants (Fig. 4.62).

Silver

All sections examined demonstrated a thin layer of fibrous tissue immediately adjacent to the implant in Zones 1 and 2. Within Zone 1, the cortical bone facing the implant demonstrated a smooth margin with evidence of bony remodelling, evidenced by an altered staining pattern.

Platinum

In sections from one animal, the cortical bone appeared to be very thin, with focal areas of direct bone apposition to the implant. In the other two specimens, the cortex was seen to consist of an identifiable thickness of compact bone, with focal areas of direct bone to metal apposition. In other areas, a thin layer of fibrous tissue was interposed between the implant and the surrounding cortical bone. Evidence of bony remodelling was seen along the margin of the cortical bone facing the implant.

Within Zone 2, small trabeculae of bone were seen in close proximity to the implant, otherwise the soft

tissues of the medullary cavity appeared to be separated from the implant by a very thin layer of fibrous tissue.

Palladium

The tissue responses seen around the palladium implants were similar to those seen around the platinum implants, except that in all three specimens, Zone 1 was seen to consist of an identifiable thickness of compact bone.

Gold alloy

The tissue responses around the gold alloy implants were similar to those seen around the platinum and palladium implants.

Macroscopic examination of one of the specimens had shown the implant to have been covered with tissue. Microscopic examination of this specimen demonstrated periosteal new bone formation over the inferior end of the implant. The cortical bone facing the length of the implant demonstrated remodelling and focal areas of apparent bone to metal apposition. Focal areas of fibrous tissue were seen along the interface with the implant (Fig. 4.63).

In addition, two of the implants were seen to have penetrated teeth. Mineralisation around dentine chips was marked in one of these specimens, and extended along the implant for a short distance. The appearance of the mineralised tissue was similar to that shown on Fig. 4.62.

Gold

The tissue responses seen around the gold implants were similar to those seen around the platinum, palladium and gold alloy implants.

b) AFTER THIRTEEN WEEKS

Copper

Gross tissue destruction and replacement with fibrous tissue was observed in all copper implant specimens. Periosteal new bone formation was seen extending along the buccal and lingual cortices (Fig. 4.64). The margins of the pre-existing bone adjacent to the implant were smooth but irregular, with infiltration by fibrous tissue.

The entire length of the copper implants was seen to be surrounded by a thick layer of fibrous tissue, arranged parallel to the surface of the implant.

Dentozyl®

Macroscopic examination of one of the Dentozyl® implants had shown that the implant was covered with tissue. Examination of this specimen under the microscope revealed that a layer of fibrous tissue surrounded the implant in Zone 1. At the inferior cortical margin, a thin layer of bone was seen peripheral to the fibrous tissue, with isolated islands of bone noticed within the fibrous tissue. The cortical bone facing the implant demonstrated a rough irregular surface, with no evidence of remodelling.

The remaining two specimens demonstrated evidence of remodelling of the cortical bone in Zone 1 adjacent to the implants. Haversian systems were evident in the bone adjacent to the implant, with osteocytes visible in lacunae (Fig. 4.65). Periosteal new bone formation was also evident. Interposed between the cortical bone and the implant, a very thin layer of fibrous tissue was seen. Focal areas of bone abutting the implant directly were apparent.

Within Zone 2, all implants were seen to have penetrated

teeth. Mineralisation was evident around the dentine chips, and in places appeared to abut the implant directly.

Silver

Sections from three specimens demonstrated areas of remodelling of the cortical bone adjacent to the implant within Zone 1, with Haversian systems being noticed in places. Focal areas of fibrous tissue were present between the implants and surrounding cortical bone. Areas of apparent direct apposition of bone to the implant were present.

One specimen was noticed to have been covered with tissue when examined at a gross level; microscopic examination of sections from this specimen revealed that the implant was covered with a layer of new bone, with some lamellae visible parallel to the inferior border of Zone 1.

Within Zone 2, a thin layer of fibrous tissue was seen surrounding the implants. The implants had penetrated the teeth in two cases, and evidence of mineralisation around the dentine chips was apparent, but was less marked than in the Dentozyl® specimens.

Platinum

All sections of the platinum implants demonstrated a similar response, namely a remodelling of the cortical bone facing the implant within Zone 1, with Haversian systems being prominent in the remodelled area.

Focal areas of fibrous tissue were present between the implant and bone; in other areas, an apparent direct bone to metal relationship existed.

Within Zone 2, the contents of the medullary cavity were seen to abut the implant, with a very thin layer of fibrous tissue at the interface.

Palladium

The responses seen around the palladium implants were essentially similar to those seen around the platinum implants.

Gold alloy

The responses seen around the gold alloy implants was similar to those seen around the platinum and palladium implants.

Macroscopic examination of two of the specimens had shown the inferior ends of the gold alloy implants to have been covered with a layer of new tissue; microscopic examination of these specimens revealed a layer of new bone formation over the implants, similar to that shown in Fig. 4.63. Evidence of bony remodelling was apparent in the cortical bone of Zone 1 facing the implants. A well-defined layer of new bone formation with Haversian systems was seen, with osteocytes present in lacunae. Evidence of periosteal new bone formation was seen in one specimen (Fig. 4.66).

Within Zone 2, the implants had penetrated teeth in two specimens, and mineralisation around the dentine chips was prominent, extending along the metal in some sections examined, and into the pulp (Figs. 4.67 and 4.68).

Gold

The responses seen around the gold implants were similar to those seen around the platinum, palladium and gold alloy implants.

New bone formation was seen over the top of two specimens, similar that shown in Fig. 4.63.

Fig. 4.62 **DENTOZYL®** **4 WEEKS**

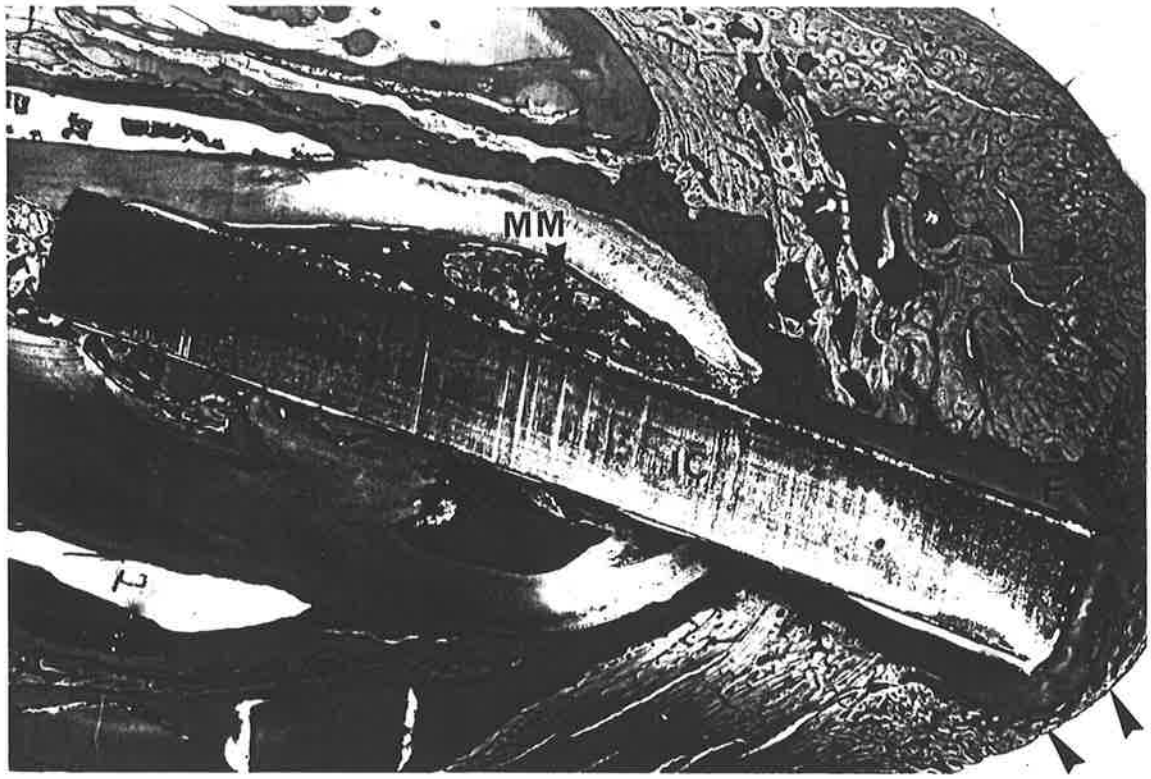
Low power photomicrograph of tissue surrounding a Dentozyl® implant. A periosteal new bone formation (arrowed) is seen at the inferior cortical margin. A layer of fibrous tissue can be seen between the implant and cortical bone. No evidence of bony remodelling is apparent within the cortical bone facing the implant. Where the implant has penetrated the tooth, a mineralised matrix (MM) surrounding dentine chips can be seen.
In this specimen, no fibrous tissue between the tooth and implant is apparent.

Modified trichrome
Original magnification x6.3

Fig. 4.63 **GOLD ALLOY** **4 WEEKS**

Photomicrograph of Zone 2 surrounding a gold alloy implant. New bone formation can be seen over the inferior margin of the implant (arrowed). Remodelling of the cortical bone adjacent to the implant is evident, as are focal areas where the cortical bone appears to abut the implant directly. Areas of fibrous tissue are interposed between the cortical bone and implant in places.
Note the artifactual split between the implant and bone.

Modified trichrome
Original magnification x20


MM

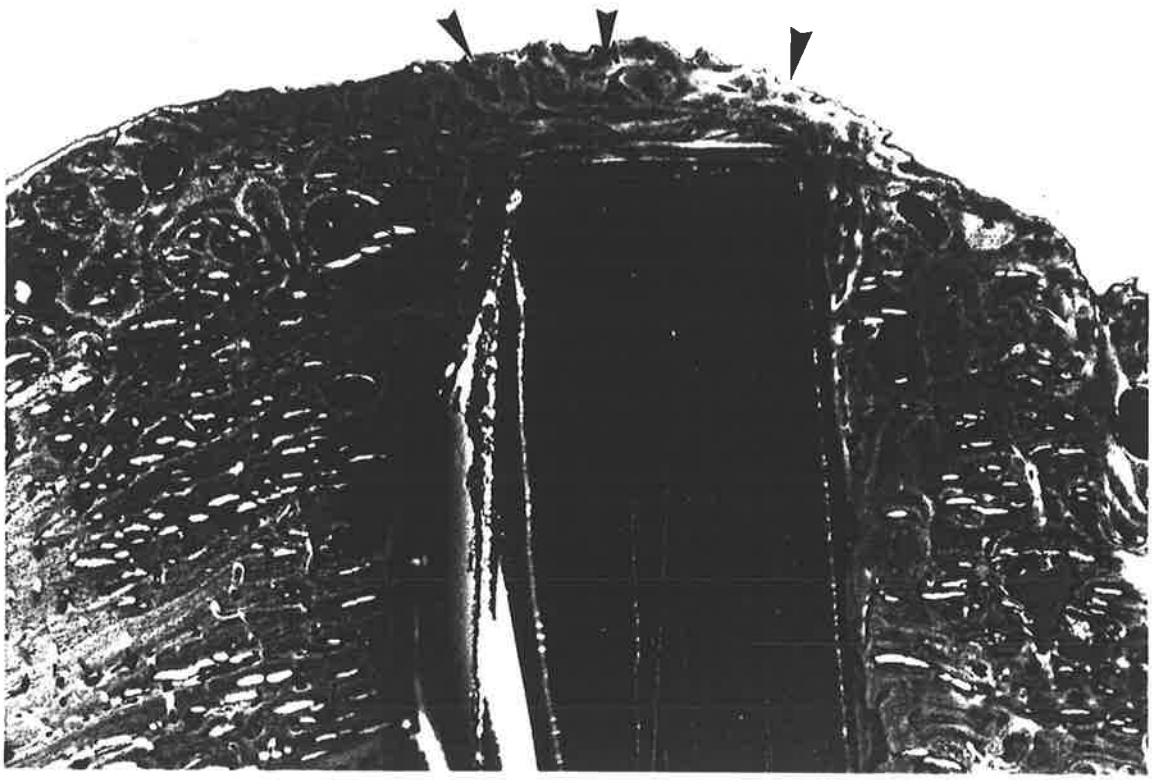


Fig. 4.64 **COPPER** **13 WEEKS**

Photomicrograph of tissue adjacent to a copper implant. Gross tissue reactions are evident. A layer of periosteal new bone formation is seen on the surface of the cortical bone, extending along the length of the buccal cortex. Necrotic debris (D) can be seen over the inferior margin of the implant. A layer of fibrous tissue is noticed around the implant, and infiltrating the peripheral cortical bone.

Modified trichrome
Original magnification x10

Fig. 4.65 **DENTOZYL®** **13 WEEKS**

Photomicrograph of Zone 1 adjacent to a Dentozyl® implant. Evidence of bony remodelling can be seen in the cortical bone facing the implant. Haversian systems (H) are present close to the implant. Direct bone to metal contact is apparent in places (arrowed ⇊). Elsewhere a thin layer of fibrous tissue is interposed between the implant and the cortical bone.
In this specimen, a small area of new periosteal bone formation is present extending along the implant (►). This corresponds to the cuff of tissue seen on macroscopic examination of the specimen.

Modified trichrome
Original magnification x16


D

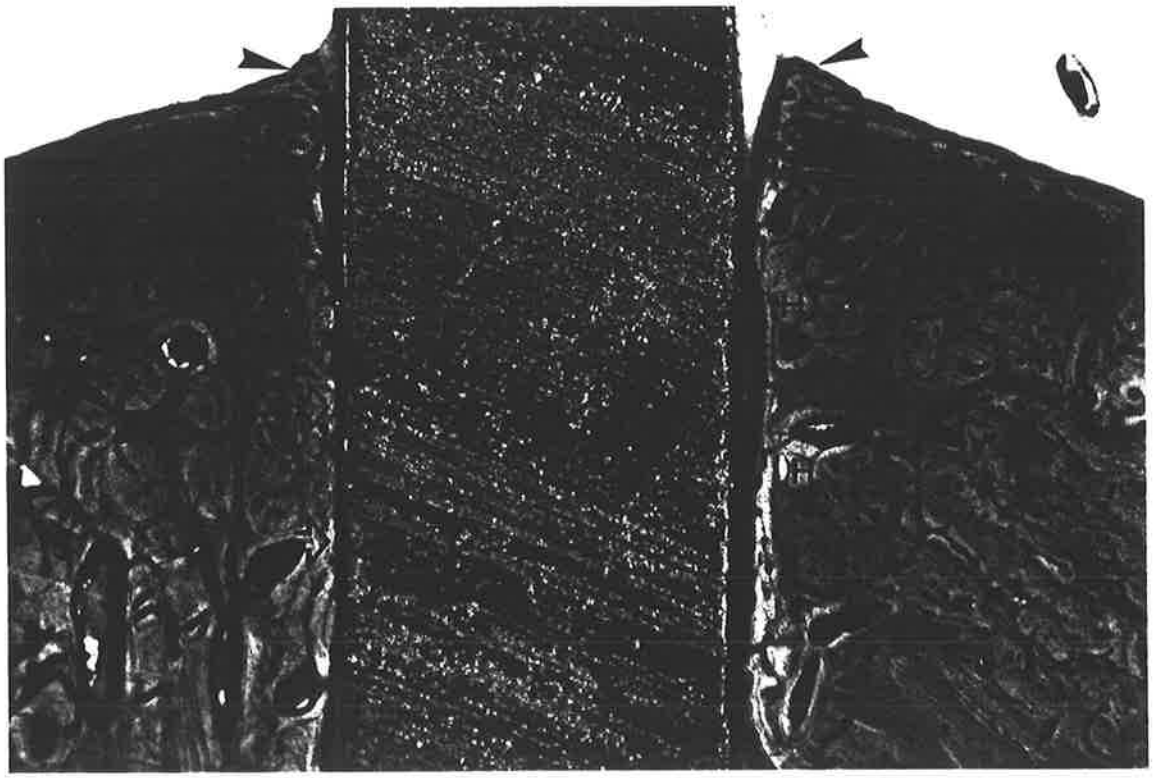


Fig. 4.66 **GOLD ALLOY** **13 WEEKS**

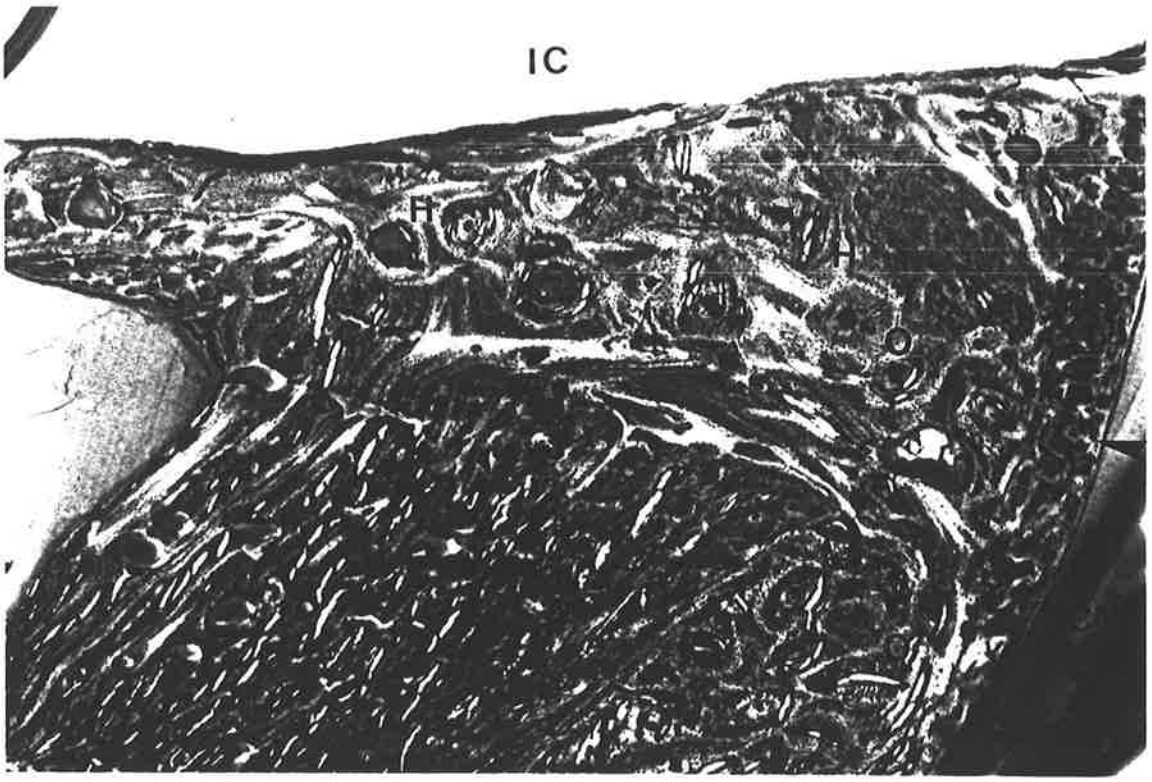
Photomicrograph of the cortical bone adjacent to a gold alloy implant. Evidence of periosteal new bone formation (arrowed) is seen at the inferior cortical margin (ICM). Bony remodelling with Haversian systems (H) is prominent in the bone facing the implant. Osteocytes (O) are seen in lacunae.
A thin layer of fibrous tissue is seen interposed between the cortical bone and the implant.
NOTE: the metal has been lost from this section during preparation.

Modified trichrome
Original magnification x20

Fig. 4.67 **GOLD ALLOY** **13 WEEKS**

Low power photomicrograph of an implant which has penetrated a tooth. Mineralisation around the dentine chips, and within the pulp is prominent, extending around the implant cavity.
NOTE: The metal has been lost in this section.

Modified trichrome
Original magnification x10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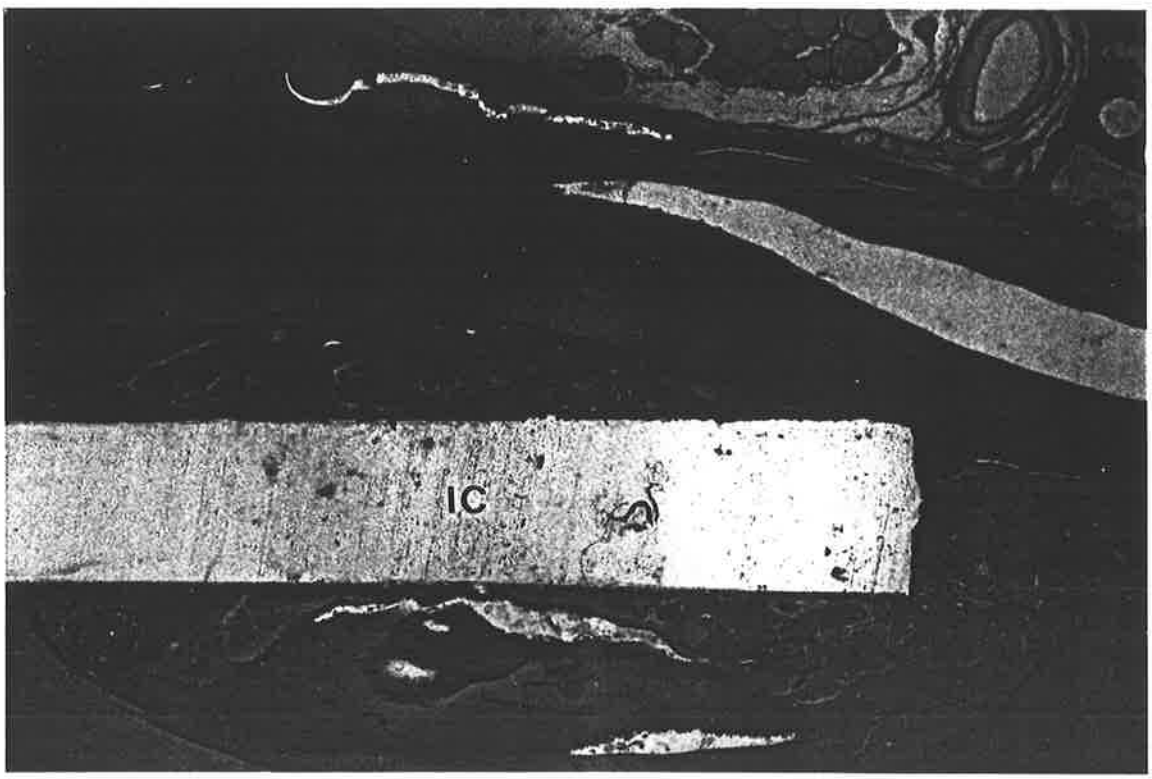
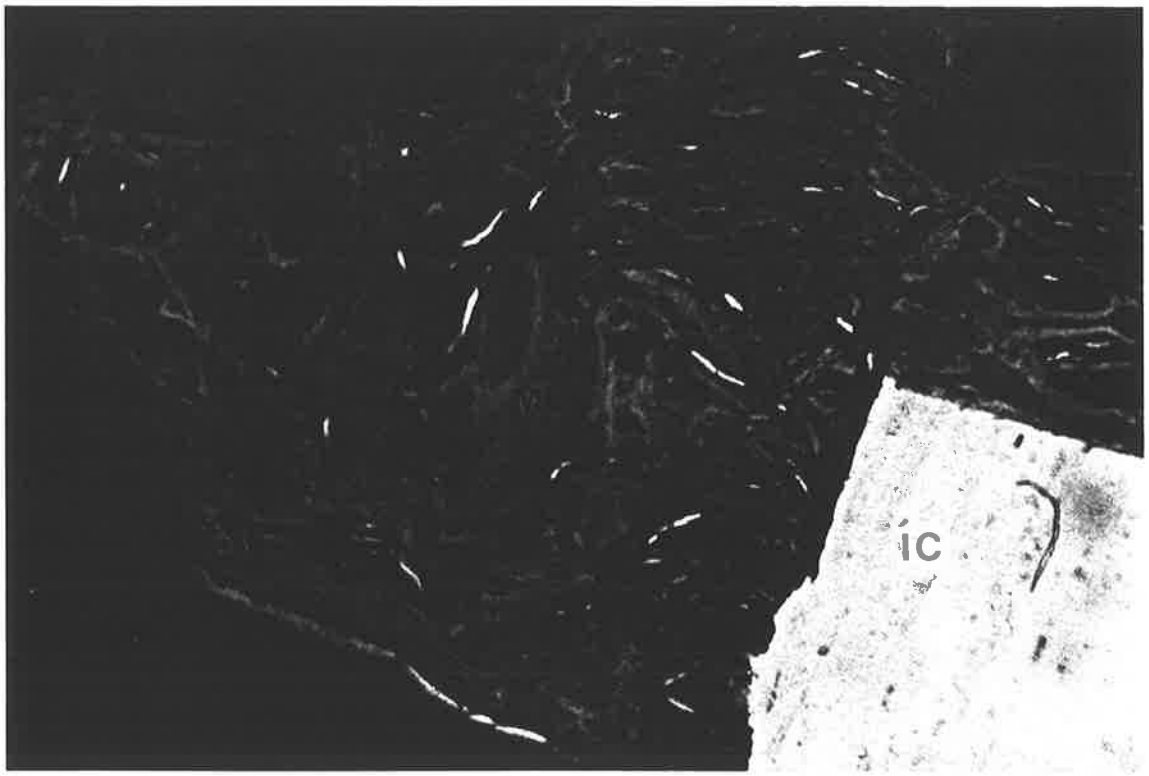

IC

Fig. 4.68 **GOLD ALLOY** **13 WEEKS**

Higher power view of the mineralised dentine chips seen in Fig. 4.67. On the left of the photo, dentinal tubules can be seen. Between these and the implant cavity, mineralisation (M) is prominent around the dentine chips (D).

Modified trichrome
Original magnification x32


ic

4.5 SCANNING ELECTRON MICROSCOPY AND ELECTRON MICROPROBE ANALYSIS

CONTROLS

All controls exhibited similar surface characteristics, namely an irregular and superficially porous surface with pore sizes ranging from 2μ to 10μ, consistent with a sand-blasting process (Figs. 4.69 and 4.70).

Occasional particles could be seen lodged in the pores (Fig. 4.71); electron microprobe analysis of the particles revealed the presence of aluminium; (Fig. 4.72).

Those controls which had been stored in formalin and decalcifying agents prior to examination demonstrated similar surface characteristics to those which had been kept in air.

a) AFTER FOUR WEEKS

Copper

The original surface detail of the metal was no longer visible; the surface consisted of an irregular granular surface with occasional crystalline structures (Fig. 4.73).

Electron microprobe analysis recorded the presence of phosphorus, chlorine and calcium, in addition to copper (Fig. 4.74).

Dentozyl®

A thin coating over the entire implant was present, but the surface pores and irregularities of the metal could still be distinguished. Irregularly spaced clusters of material could be seen on the surface; some was amorphous, other parts fibrillar (Fig. 4.75). Most prominent were spherical objects with diameters between 3μ and 5μ. These had two distinct types of surface characteristics; a closely packed and a more loosely

arranged honeycomb appearance.
Electron microprobe analysis of the implant surface confirmed the presence of the main constituent elements of the alloy (gold, silver, palladium, platinum and copper) to be present (Fig. 4.76). Electron microprobe analysis of the spherical objects on the surface recorded the presence of calcium and phosphorus (Fig. 4.77).

Silver

Examination of the surface of the silver implant showed the presence of an amorphous layer, on top of which were subspherical and equant shaped matter. The original surface detail was no longer visible over the majority of the metal (Figs. 4.78 and 4.79).
Electron microprobe analysis of the subspherical deposits revealed the presence of silver, chlorine, sulphur and phosphorus (Fig. 4.80). That of the equant crystals showed silver, chlorine and sulphur (Fig. 4.81).

Platinum

At low magnification, a surface coating over the implant could be seen. At higher power, the surface pores and irregularities could still be seen. An occasional cell-like structure with irregular extensions was present on the surface (Fig. 4.82).
Irregularly spaced spherical and equant deposits were noted on the surface. Analysis with the electron microprobe recorded the presence of calcium and phosphorus in these structures. Electron microprobe analysis of the implant surface recorded the presence of platinum (Fig. 4.83).

Palladium

At low magnification a coating over the entire implant was visible. At higher magnifications, striations in the

metal were evident, together with irregularly shaped deposits on the surface. The surface itself was little changed from that of the control (Fig. 4.84).
Electron microprobe analysis of these surface deposits showed calcium and phosphorus to be present; that of the surface recorded the presence of palladium.

Gold alloy

At low magnifications, a coating over the implant was present as demonstrated by the surface shadows caused by incomplete electron penetration. The surface structure of the gold alloy was essentially unchanged from that of the control (Fig. 4.85), but occasional irregularly shaped bodies of material, approximately 5μ by 5μ were seen.
Electron microprobe analysis of the implant surface recorded the presence of gold, silver, platinum and copper (Fig. 4.86); that of the small surface bodies recorded calcium and phosphorus.

Gold

At low magnifications an organic coating was visible over the entire implant surface, with retention of the original surface morphology (Fig. 4.87). At higher magnifications, striations in the metal surface were noted.
Occasional spherical bodies approximately 5μ diameter were visible on the surface; these contained calcium and phosphorus on electron micrprobe analysis. Analysis of the implant surface recorded only the presence of gold.

A summarised form of the results obtained after four weeks is shown in Table 4.1.

b) AFTER THIRTEEN WEEKS

Copper

An irregular granular appearance of the implant surface was apparent at all magnifications, with a few spherical deposits, approximately 3μ diameter, seen on the surface. Also present on the surface were embedded fragments with a regular outline, approximately 10μ by 4μ, shown to contain aluminium on microprobe analysis (Fig. 4.88).

Electron microprobe analysis of the spherical deposits showed copper and chlorine to be the main elements present, together with smaller amounts of phosphorus (Fig. 4.89). This finding, together with the irregular granular nature of the surface would suggest a fluid chemical etching of the implant, yielding a copper chloride residue.

Dentozyl®

At low magnifications, an organic coating was present over the surface of the implant. At higher power no surface deposits could be seen; surface striations were noted; otherwise the appearance was unchanged from that of the control (Fig. 4.90).

Electron microprobe analysis of the surface recorded the presence of gold, palladium, platinum, silver and copper.

Silver

Scanning electron microscopic examination showed irregular granular deposits over most of the surface (Fig. 4.91). These contained silver, chlorine, and small amounts of sulphur upon electron microprobe analysis (Figs. 4.92 and 4.93).

Platinum

A thin organic coating was present on the surface. No chemical etching was apparent, but occasional small

irregular clusters of fibrous material were seen (Fig. 4.94).
Electron microprobe analysis of the surface recorded the presence of platinum.

Palladium
The surface detail at thirteen weeks was very similar to that of the control sample. A few small crystalline deposits were seen on the surface (Fig. 4.95); these were shown to contain calcium and phosphorus on electron microprobe analysis.

Gold alloy
A thin organic coating was present over the entire implant surface, otherwise examination at low and high power showed the surface detail to be unchanged from that of the control. No chemical etching was apparent (Fig. 4.96).
Electron microprobe analysis of the surface revealed the presence of the constituent elements of the alloy, namely gold, silver, copper and platinum (Fig. 4.97).

Gold
A thin organic coating was evident over the surface of the implant. No surface deposits were present and no chemical etching was apparent (Fig. 4.98).
Electron microprobe analysis recorded the presence of gold and a small amount of aluminium.

A summarised form of these results is shown in Table 4.2

Metal	Organic coating	Granular deposits		Surface morphology change
		Ca/P rich	Cl rich	
Copper	–	–	++	++
Dentozyl®	+	–	–	–
Silver	–	–	++	++
Platinum	+	(+)	–	–
Palladium	+	(+)	–	–
Gold alloy	+	–	–	–
Gold	+	–	–	–

Table 4.1 Summary of the surface appearances of the implants materials after four weeks.

Metal	Organic coating	Granular deposits		Surface morphology change
		Ca/P rich	Cl rich	
Copper	–	+	+	++
Dentozyl®	+	+	–	–
Silver	+	+	+	+
Platinum	+	+	–	–
Palladium	+	+	–	–
Gold alloy	+	+	–	–
Gold	+	+	–	–

Table 4.2 Summary of the surface appearances of the implant materials after thirteen weeks.

Fig. 4.69 **CONTROL**

Scanning electron micrograph of the surface of a gold alloy implant. All metals showed similar surface characteristics.

Fig. 4.70 **CONTROL**

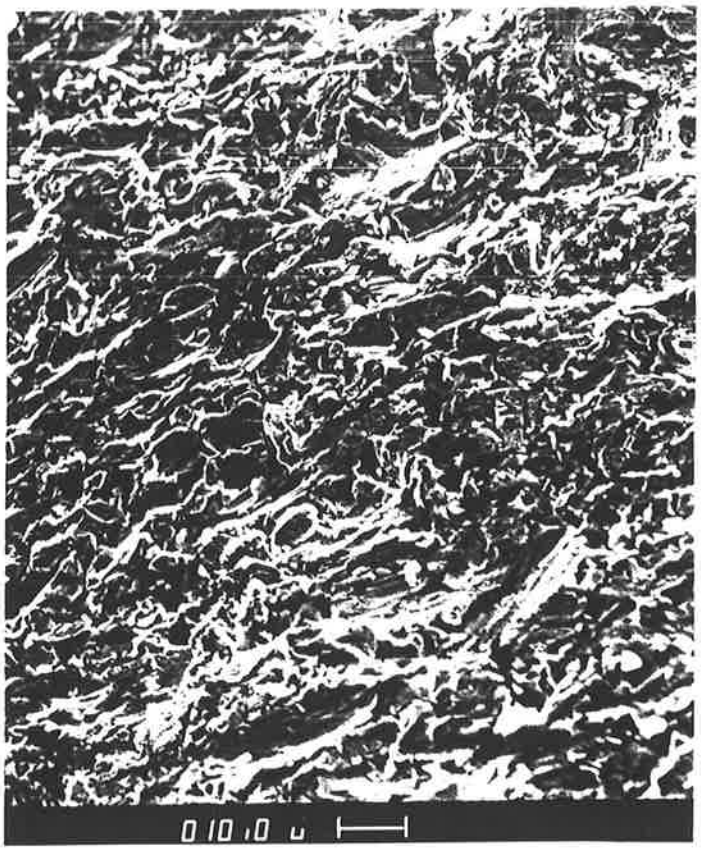
Higher power view of the surface of a Dentozyl® implant.

Fig. 4.71 **CONTROL**

Scanning electron micrograph of a one of the particles occasionally seen lodged in the pores of the control implants. Electron microprobe analysis of this particle recorded the presence of aluminium.

Fig. 4.72 **CONTROL**

Computer print-out of the analysis of the particle shown in Fig. 4.71. The presence of aluminium is recorded; since only elements whose atomic number is greater than eleven can be recorded, this is presumably Al_2O_3 from the surface sand blasting process.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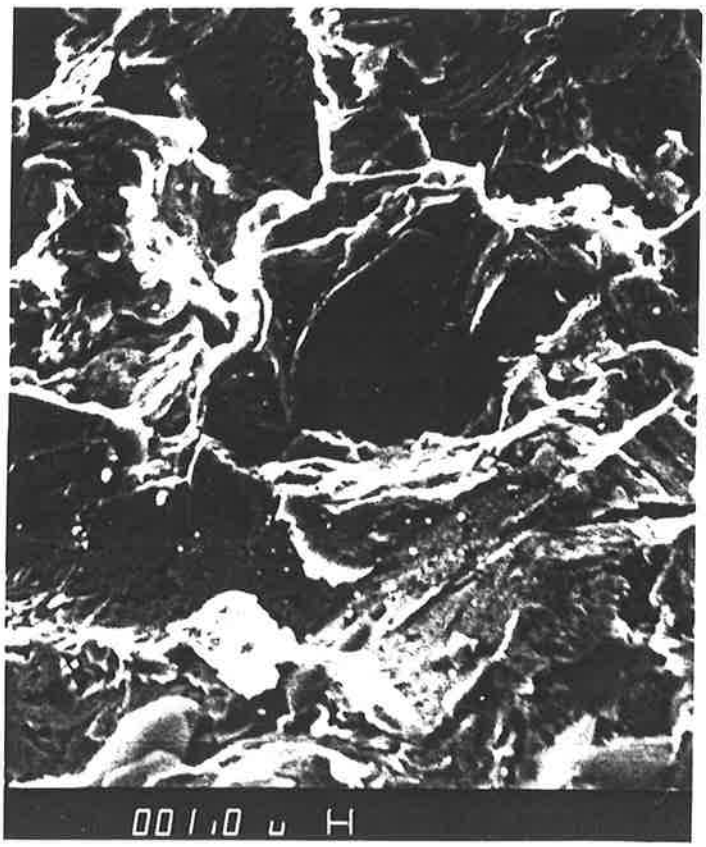
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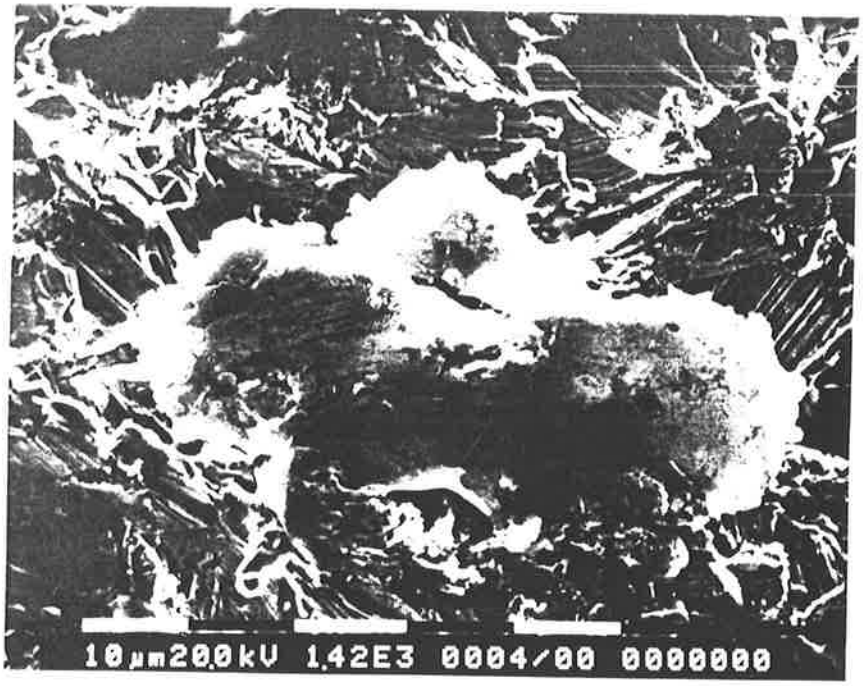
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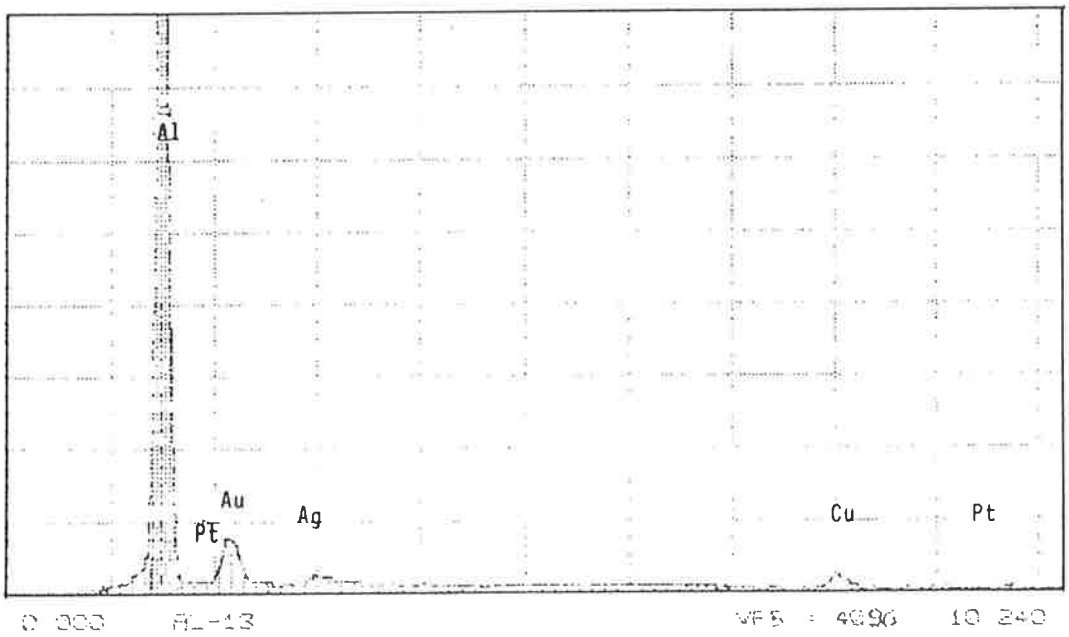
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Au
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0.000 AL-13
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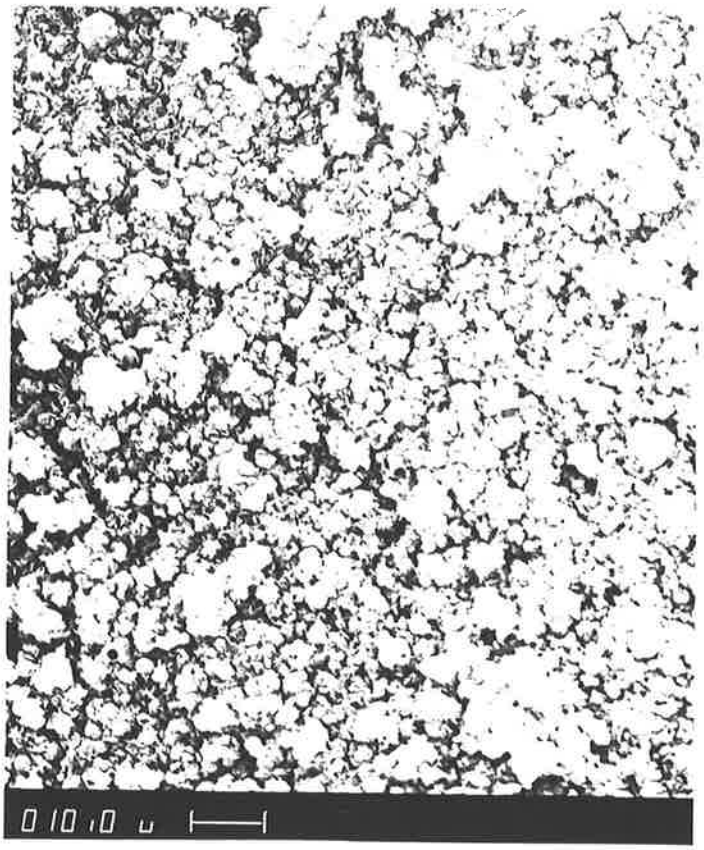
Fig. 4.73 COPPER 4 WEEKS

Scanning electron micrograph of the surface of the copper implant, seen to consist of an irregular granular surface. Electron microprobe analysis (EMPA) of this surface recorded the presence of phosphorus, chlorine and calcium, in addition to copper.

Fig. 4.74 COPPER 4 WEEKS

Computer print-out of EMPA of the surface of the copper implant after four weeks implantation.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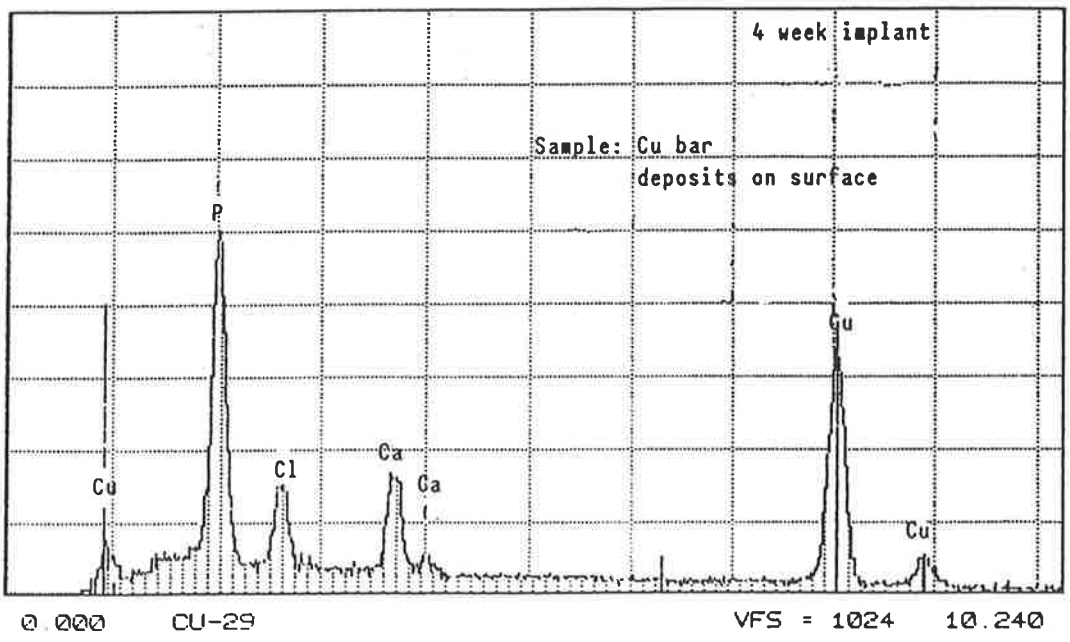

4 week implant
Sample: Cu bar
deposits on surface
P
Cu
Cl
Ca
Ca
Cu
Cu
0.000
CU-29
VFS = 1024
10.240

Fig. 4.75 **DENTOZYL®** **4 WEEKS**

Scanning electron micrograph of the surface of the Dentozyl® implant after four weeks. The shadowing effect is due to a thin organic coating over the surface. Surface pores and irregularities can still be distinguished, as can amorphous clusters of material on the surface (arrowed).
Spherical objects, with diameters of between 3u and 5u are prominent on the surface. Two types of surface characteristics can be distinguished on the objects; a closely packed arrangement (CP) and a more loosely arranged honeycomb appearance (H).

Fig. 4.76 **DENTOZYL®** **4 WEEKS**

EMPA print-out of the surface of the Dentozyl® implant, demonstrating the presence of its constituent metals.


H
CP
001.0 u H

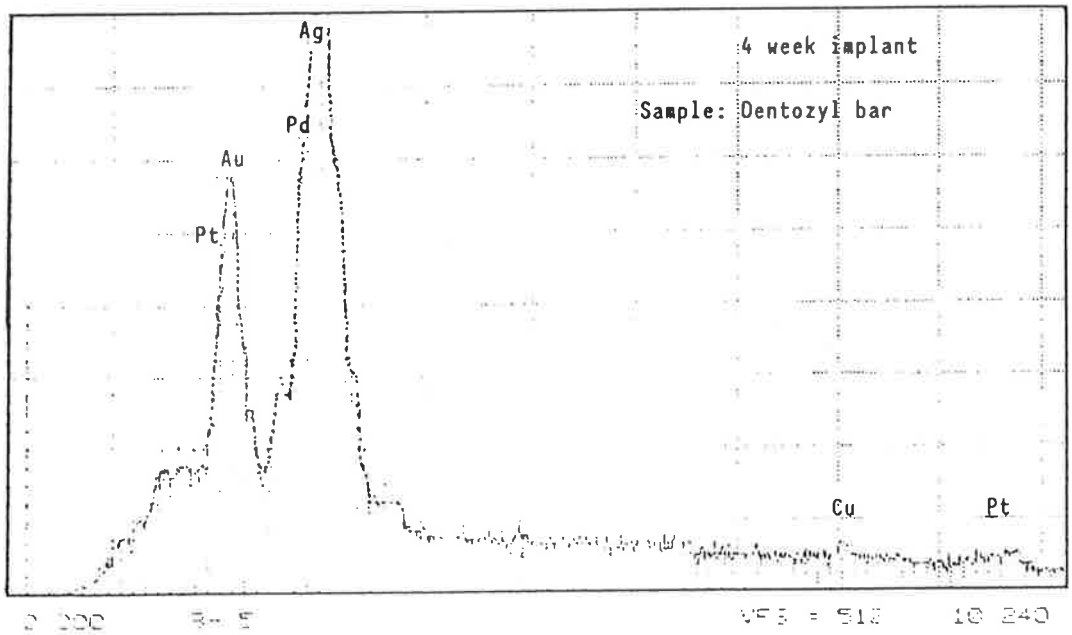
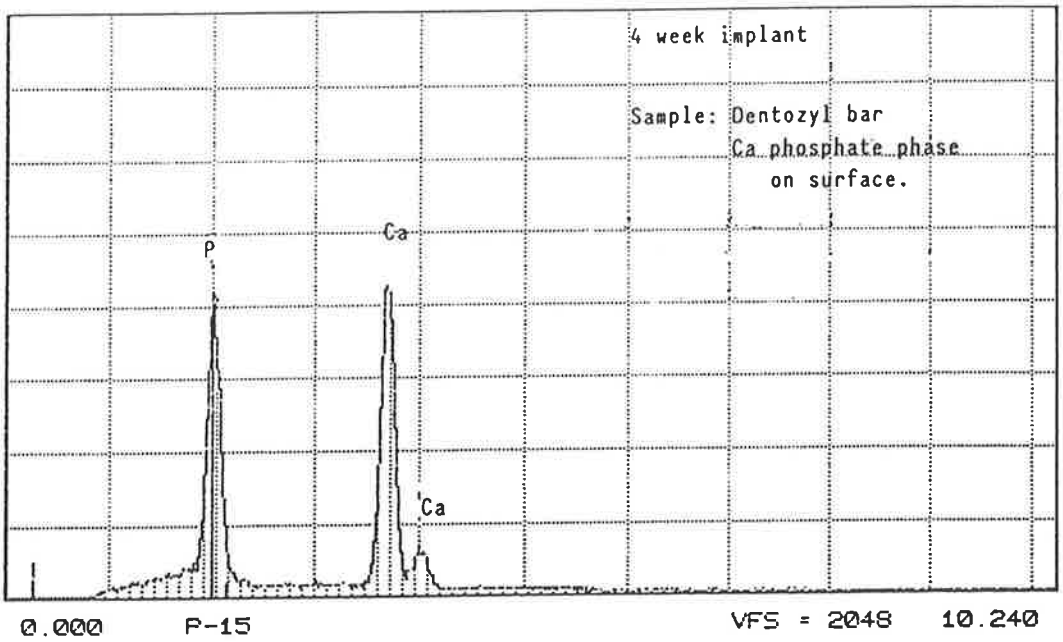

Ag
Pd
Au
Pt
4 week implant
Sample: Dentozyl bar
Cu
Pt

Fig. 4.77 **DENTOZYL®** **4 WEEKS**

EMPA print-out of the spherical objects shown in Fig. 4.75. Calcium and phosphorus are the elements recorded. Qualitative analysis records the presence of matter in elemental form; no information can be obtained as to the valence state or bonding form.

Fig. 4.78 **SILVER** **4 WEEKS**

Scanning electron micrograph of the surface of a silver implant after four weeks. A thin organic coating over much of the surface is present, and the surface morphology is less obvious than that of the control.
Spherical objects can be seen in clusters on the surface.


4 week implant
Sample: Dentozyl bar
Ca phosphate phase
on surface.
P
Ca
Ca
0.000
P-15
VFS = 2048
10.240

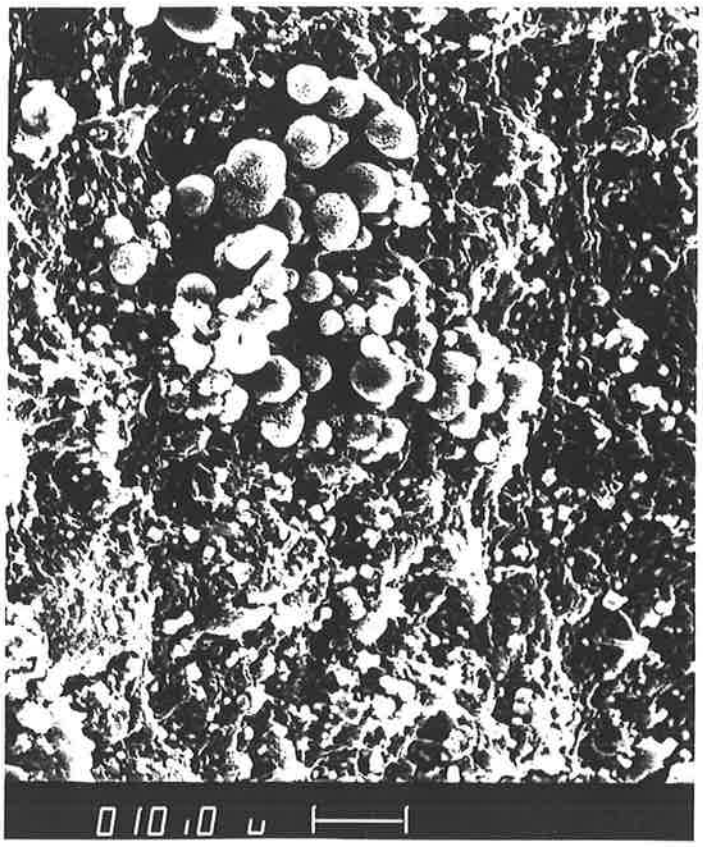
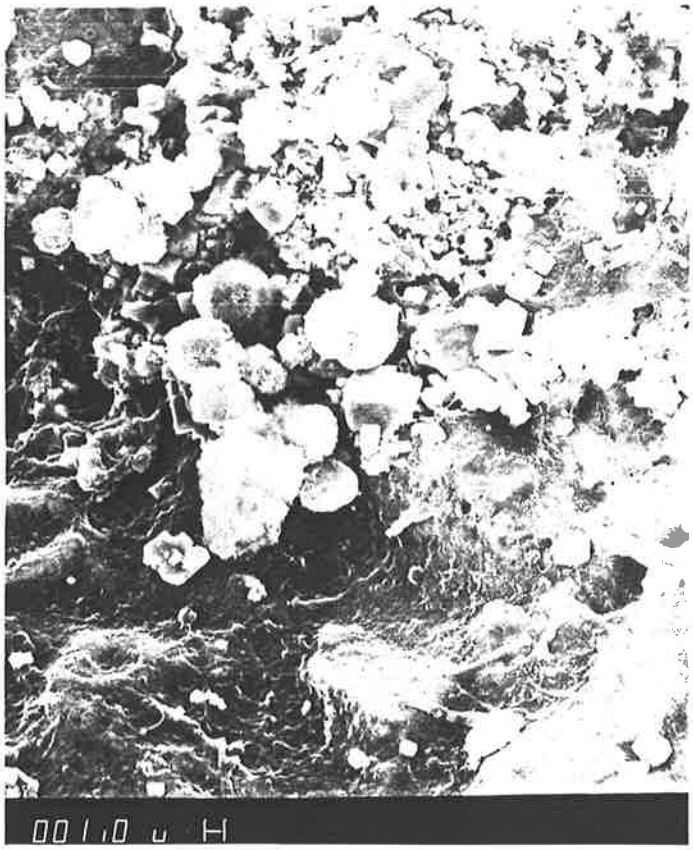

010,0 u

Fig. 4.79 **SILVER** **4 WEEKS**

Higher power micrograph demonstrating subspherical and equant shaped material on the surface of the silver implant. The surface contour of the equant shaped matter is smooth; that of the subspherical matter demonstrates a honeycomb appearance.

Fig. 4.80 **SILVER** **4 WEEKS**

EMPA print-out of the subspherical deposits on the surface of a silver implant after four weeks implantation.


001.0 u H

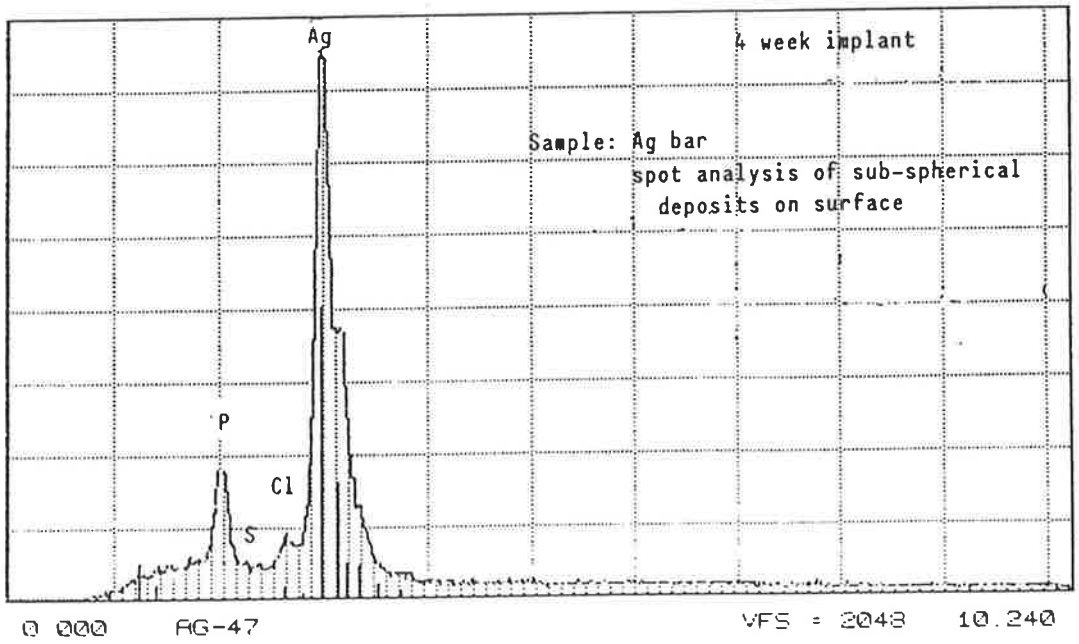
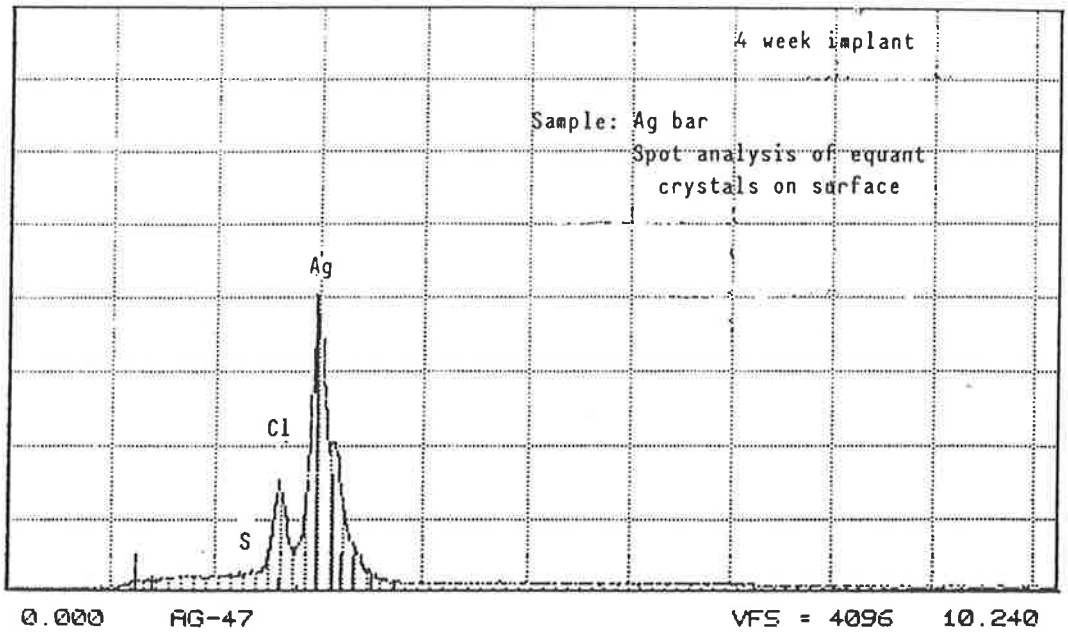

Ag
4 week implant
Sample: Ag bar
spot analysis of sub-spherical
deposits on surface
P
Cl
S
0 000
AG-47
VFS = 2048
10.240

Fig. 4.81 **SILVER** **4 WEEKS**

EMPA print-out of the equant crystals on the surface of a silver implant after four weeks implantation. A similar recording was obtained from the areas of the surface virtually free of granular deposits.

Fig. 4.82 **PLATINUM** **4 WEEKS**

Scanning electron micrograph of the surface of a platinum implant after four weeks implantation. The original surface pores and irregularities are still evident. A cell-like structure with extensions (arrowed) is visible on the surface, with a spherical object 8μ diameter on its surface.


4 week implant
Sample: Ag bar
Spot analysis of equant
crystals on surface
Ag
Cl
S
0.000
AG-47
VFS = 4096
10.240

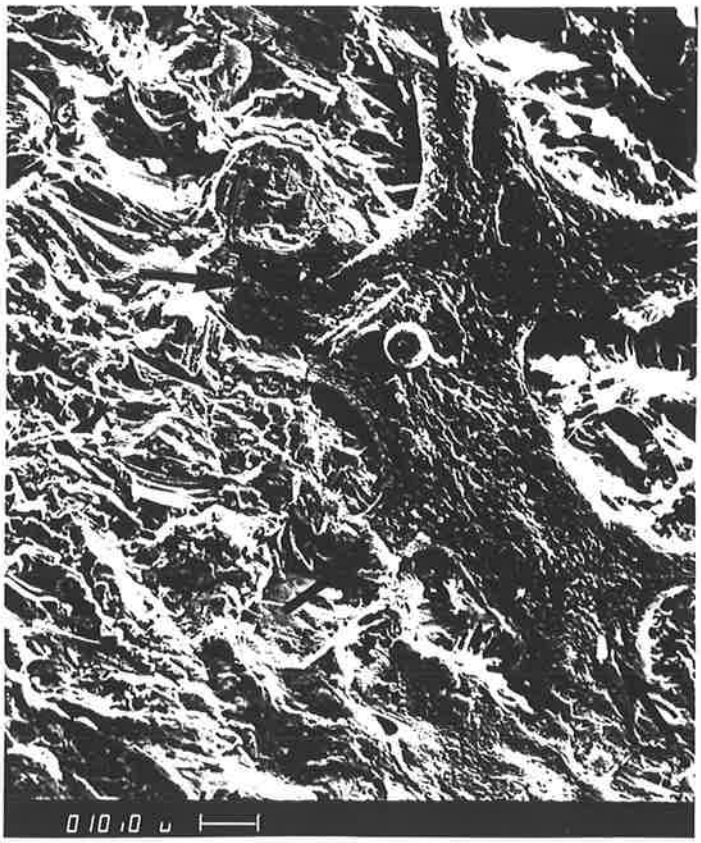
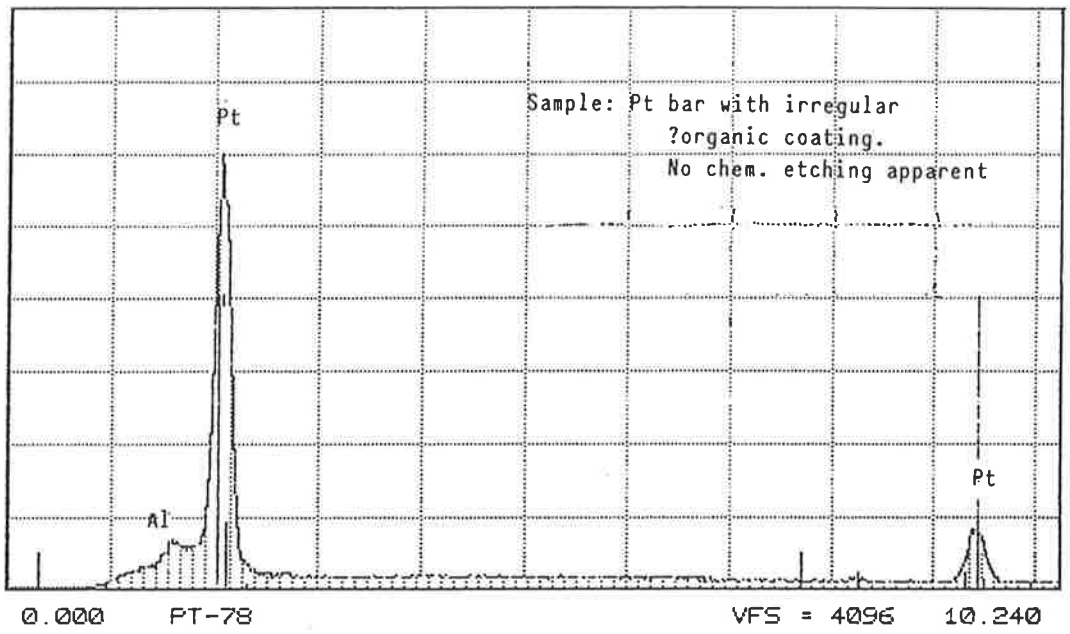

010.0 u

Fig. 4.83 **PLATINUM** **4 WEEKS**

EMPA print-out of the surface of a platinum implant after four weeks implantation.

Fig. 4.84 **PALLADIUM** **4 WEEKS**

Scanning electron micrograph of the surface of a palladium implant after four weeks implantation. The original surface morphology has been maintained and occasional irregular deposits are present on the surface (arrowed). EMPA of these deposits recorded the presence of calcium and phosphorus.


Sample: Pt bar with irregular
?organic coating.
No chem. etching apparent
Pt
Al
Pt
0.000
PT-78
VFS = 4096
10.240

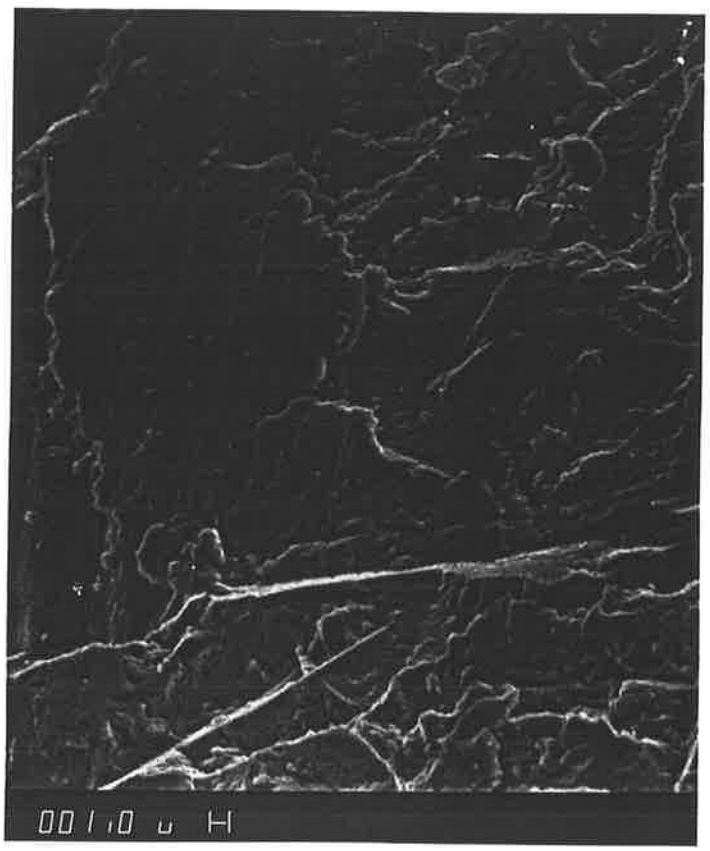
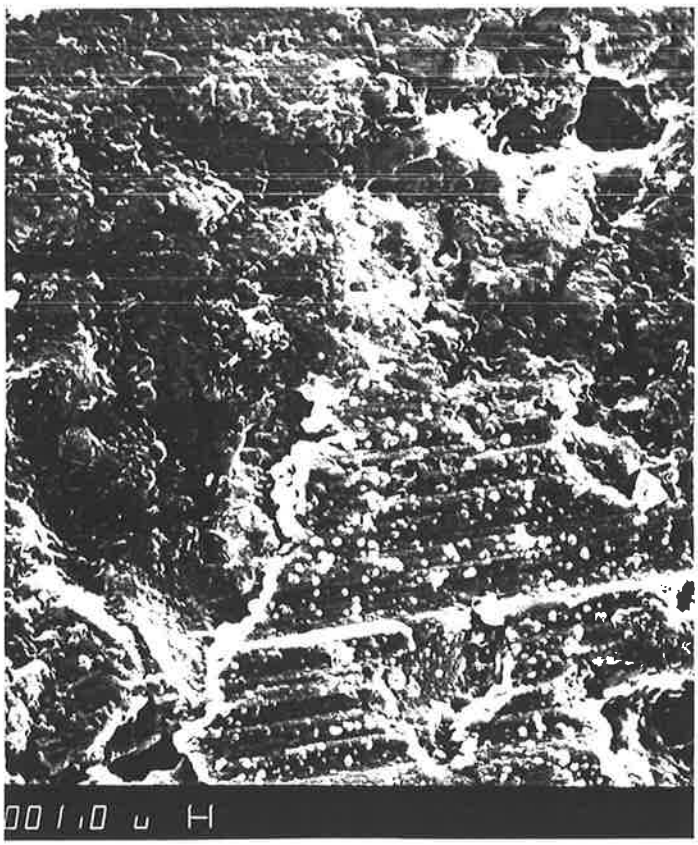


Fig. 4.85 **GOLD ALLOY** **4 WEEKS**

Scanning electron micrograph of the surface of a gold alloy implant after four weeks implantation. The original surface morphology is still visible underneath a thin organic coating.

Fig. 4.86 **GOLD ALLOY** **4 WEEKS**

EMPA print-out of the surface composition of the gold alloy implant after four weeks implantation.


00 1.0 u H

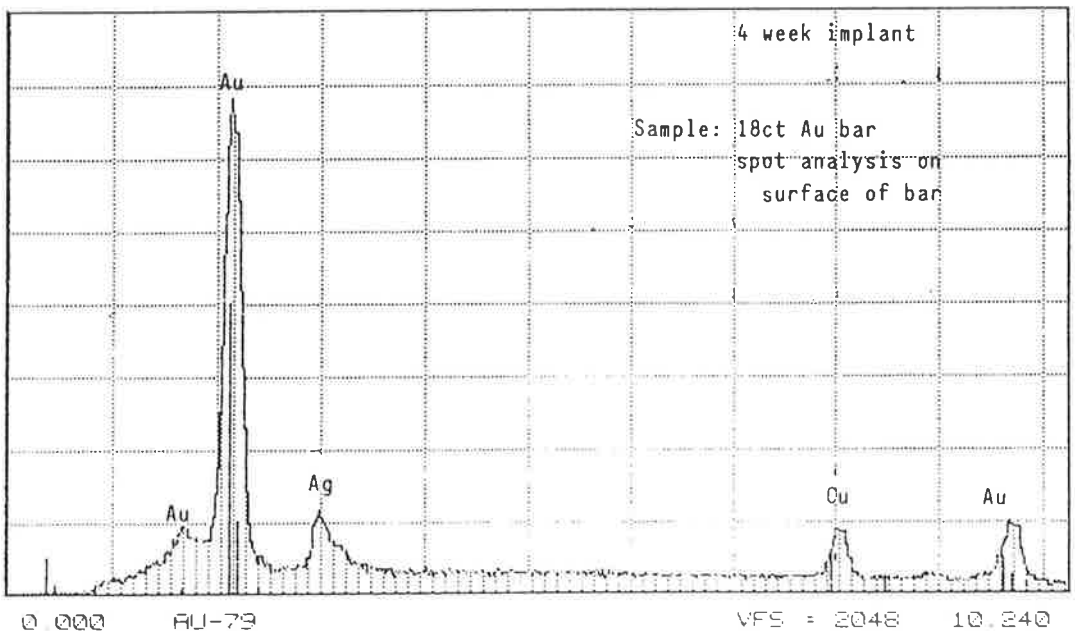

4 week implant
Sample: 18ct Au bar
spot analysis on
surface of bar
Au
Au
Ag
Cu
Au
0.000
AU-79
VFS = 2048
10.240

Fig. 4.87 **GOLD** **4 WEEKS**

Scanning electron micrograph of the surface of a gold implant after four weeks implantation. The original surface detail of irregular superficial pores can still be seen beneath a thin organic coating. Clusters of spherical bodies approximately 3μ in diameter can be seen on the surface: EMPA recorded the presence of calcium and phosphorus.

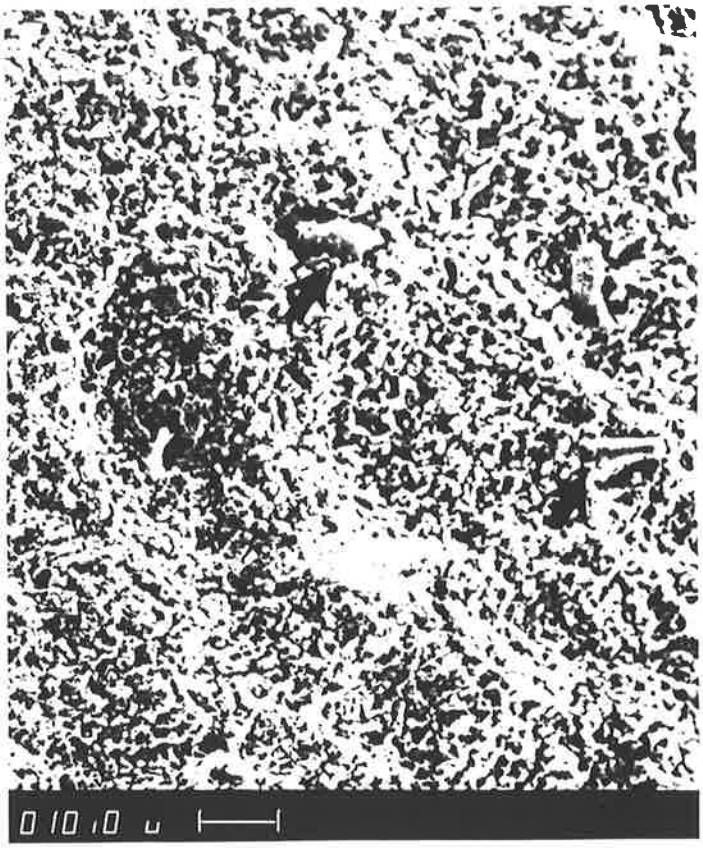

00110 u H

Fig. 4.88 **COPPER** **13 WEEKS**

Scanning electron micrograph of the surface of a copper implant recovered after thirteen weeks implantation, showing complete loss of original surface morphology. The surface is irregular and granular, with embedded fragments seen (arrowed). EMPA of the fragments recorded the presence of aluminium in some; in others copper and chlorine were the main elements present.

Fig. 4.89 **COPPER** **13 WEEKS**

EMPA print-out of the composition of the surface of a copper implant after thirteen weeks implantation.


0 10.0 u

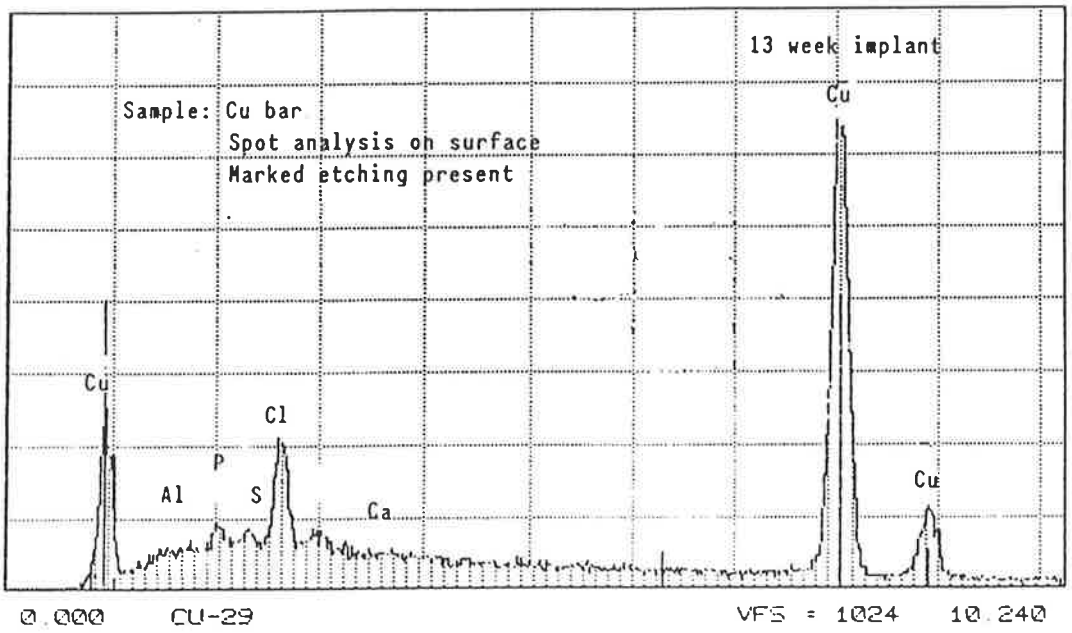

13 week implant
Sample: Cu bar
Spot analysis on surface
Marked etching present
Cu
Cu
Cl
P
Al
S
Ca
Cu
0.000
CU-29
VFS = 1024
10.240

Fig. 4.90 **DENTOZYL®** **13 WEEKS**

Scanning electron micrograph of the surface of a Dentozyl® implant after thirteen weeks implantation. The original surface morphology is still clearly visible under a thin organic layer. No rounding off of the edges of the superficial pores can be seen.

Fig. 4.91 **SILVER** **13 WEEKS**

Scanning electron micrograph of the surface of a silver implant after thirteen weeks implantation. Some of the original surface detail can still be seen under a thin organic coating; elsewhere the surface is covered with irregular granular deposits.


001.0 u H

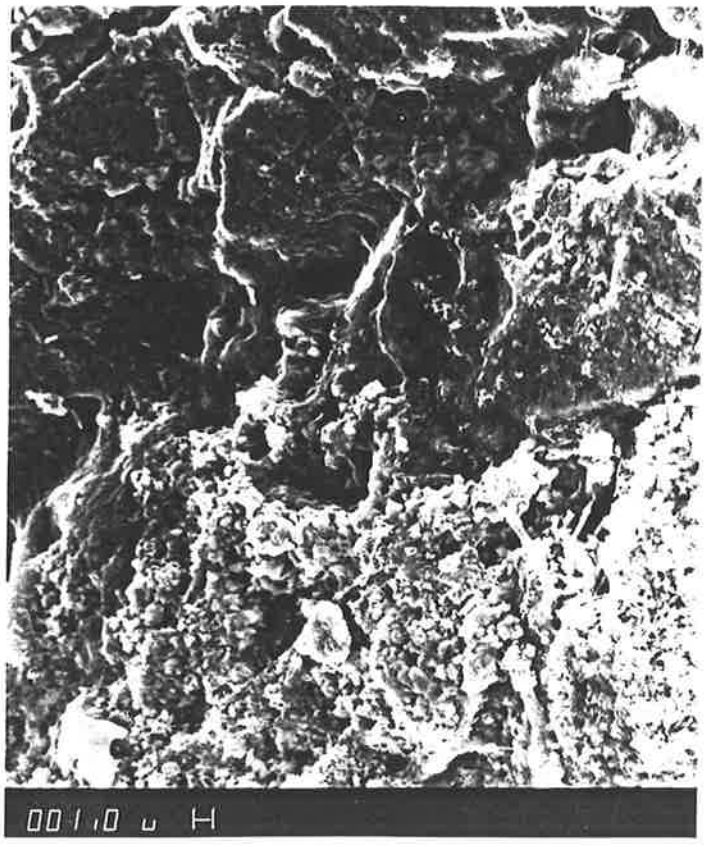
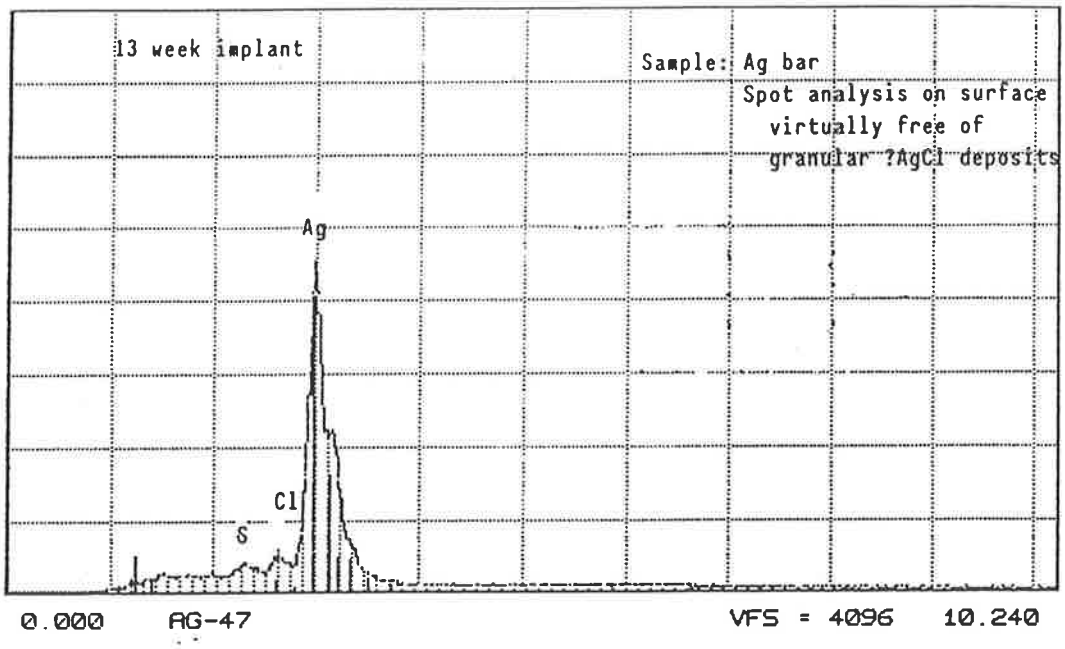

001.0 u H

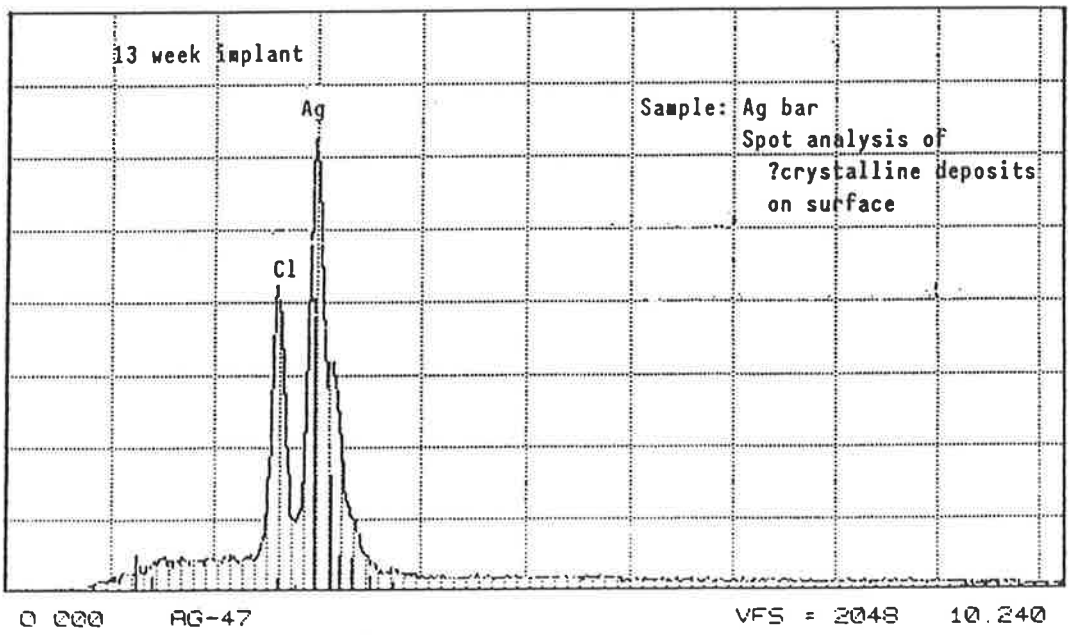
Fig. 4.92 **SILVER** **13 WEEKS**

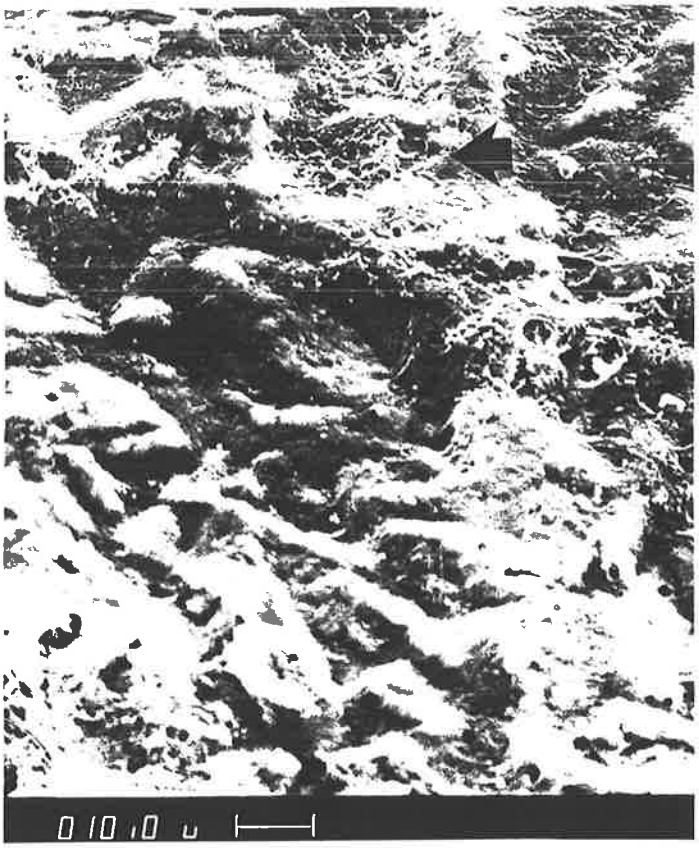
EMPA print-out of the surface components of a silver implant from an area virtually free of granular surface deposits after thirteen weeks implantation.

Fig. 4.93 **SILVER** **13 WEEKS**

EMPA print-out of the analysis of the crystalline surface deposits seen on the surface of a silver implant after thirteeen weeks implantation.


13 week implant
Sample: Ag bar
Spot analysis on surface
virtually free of
granular ?AgCl deposits
Ag
Cl
S
0.000
AG-47
VFS = 4096
10.240


13 week implant
Sample: Ag bar
Spot analysis of
?crystalline deposits
on surface
Ag
Cl
0.000
AG-47
VFS = 2048
10.240


0 10 ,0 u

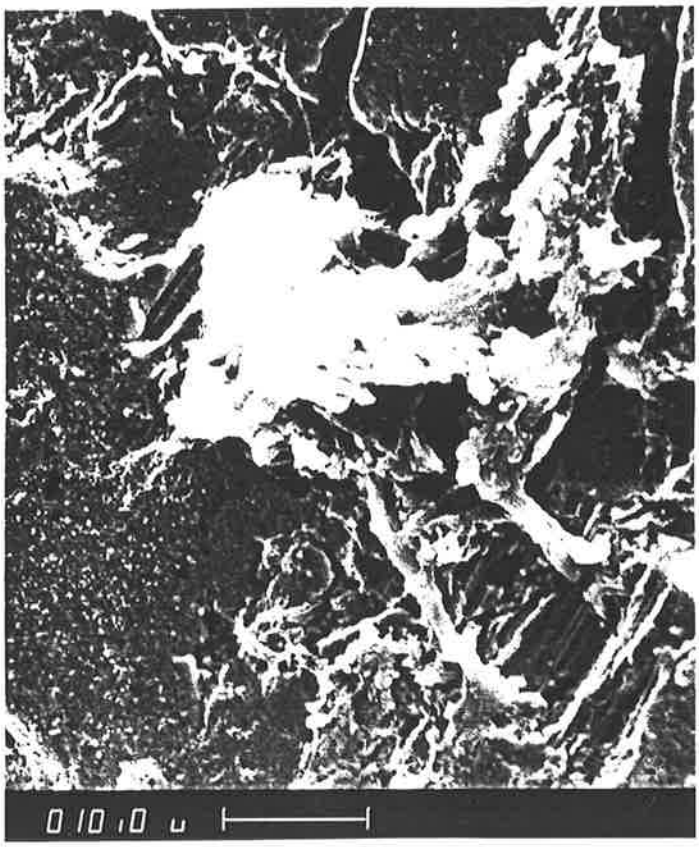
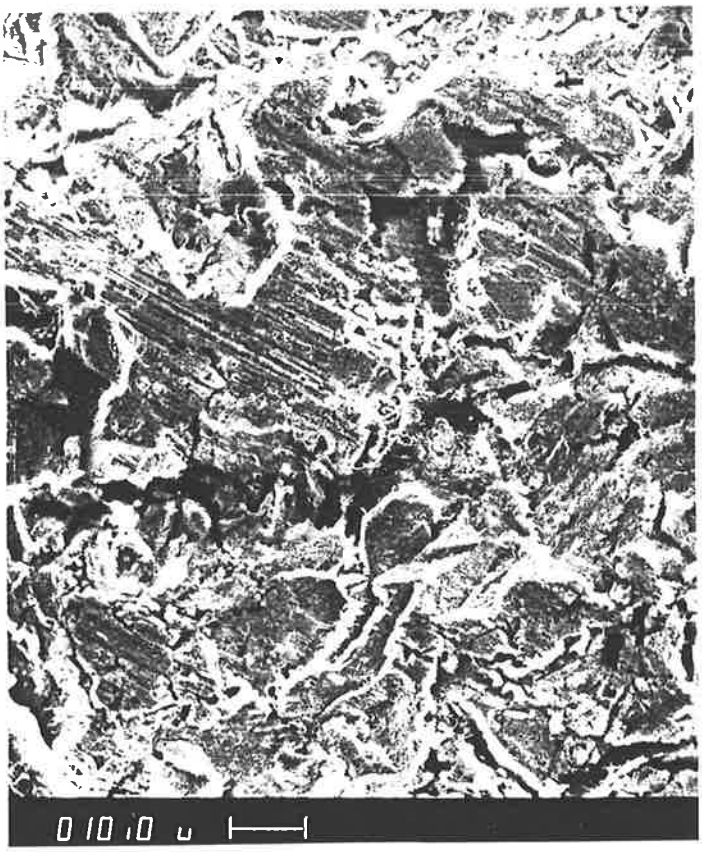

0 10 ,0 u

Fig. 4.96 **GOLD ALLOY** **13 WEEKS**

Scanning electron micrograph of part of the surface of a gold alloy implant after thirteen weeks implantation. The original surface details are still present, with well-defined edges to the superficial pores.

Fig. 4.97 **GOLD ALLOY** **13 WEEKS**

EMPA print-out of the composition of the surface of the gold alloy implant after thirteen weeks implantation. No other elements than the alloy's constituents are present.


0 10 10 u

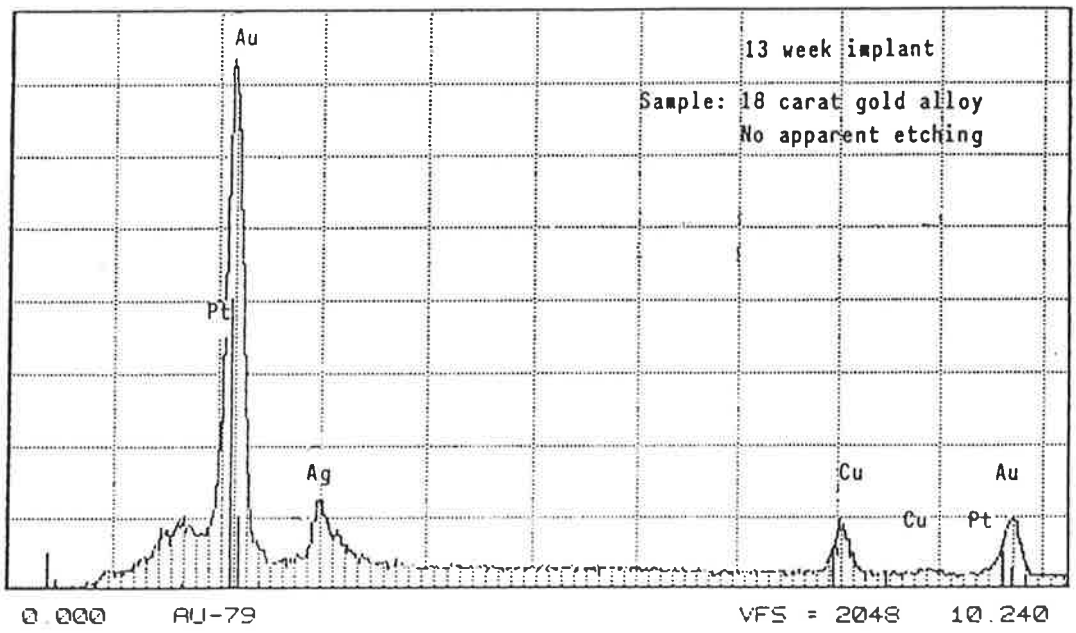

Au
13 week implant
Sample: 18 carat gold alloy
No apparent etching
Pt
Ag
Cu
Au
Cu
Pt
0.000
AU-79
VFS = 2048
10.240

Fig. 4.98 **GOLD** **13 WEEKS**

High power scanning electron micrograph of part of the surface of a gold implant after thirteen weeks implantation. The original surface detail is still visible, with well-defined edges to the superficial pores. A thin organic coating is present in places (arrowed).


001.0 u H

CHAPTER 5 DISCUSSION

5.1 THE SHEEP AS AN EXPERIMENTAL ANIMAL

The sheep proved to be a good animal for implantation purposes:- the mandible was of a size to allow placement of an adequate size and number of metal implants. The sheep was easily anaesthetised using cannulation of the external jugular vein followed by catheterisation of a leg vein with an in-dwelling catheter. During anaesthesia, the animal responded in a predictable fashion. Only one anaesthetic emergency occurred, when one animal suffered a cardiac arrest during surgery; this was quickly diagnosed and the animal was resuscitated using external cardiac compression. It recovered fully, surgery was completed and the animal's post-operative progress was uneventful. Maintenance doses of anaesthetic were easily administered intra-operatively via the in-dwelling catheter. Maintenance of an adequate airway was not a problem, and it was not necessary to intubate any animal during surgery.

The size of the sheep's mandible meant that surgical techniques used by the operator during human surgery were easily adaptable for use in the sheep. No additional surgical skills were needed, and no special instruments were required for the surgery.

There were no complications during the immediate post-operative phase. All the sheep recovered quickly and were able to be returned to the holding pens rapidly. None was observed to have any functional loss due to damage of the facial nerve. No animal appeared at any time to be in distress; all appeared to eat and drink normally post-operatively, with no change in urine output. No animal developed any frank infection post-operatively.

A review of the literature regarding animal studies has shown that the dog and the monkey have been the animals most frequently used in implant studies (Table 1.2, Chapter 1). The findings of the present study would indicate that the sheep is a suitable alternative in terms of availability, cost, maintenance and ease of anaesthesia and surgical techniques.

5.2 DESIGN OF THE EXPERIMENT

The experiment was designed to be part of an on-going research project in the Department of Dentistry to develop an animal model for research into the trans-mandibular implant of Bosker. It was therefore decided to place the metal implants in both sides of the mandible rather than other bones. The metals were placed in two groups and were implanted in a standard order determined from the preliminary experiment concerning electropotentials.

Discussion with technical officers in the Department of Physical and Inorganic Chemistry of the University of Adelaide showed that the development of a model, with all the possibilities eliminated of potentials arising between the metals leading to galvanic currents and corrosion, would be a major exercise in itself. The potential of two metals does not vary with distance, however the current flowing between two dissimilar metals varies in an inverse relationship with the distance (Fontana and Greene, 1967). In the present experiment, any current flowing between metals would not be able to be measured with great accuracy since the current varies with time and the amount of previous corrosion and surface passivation. Further, the equipment necessary to measure the current would render the experiment inhumane. From these discussions, a

preliminary experiment was developed to determine the metals' potentials with respect to a standard electrode. As bone acts as an insulator, the metals were placed in bone to simulate the major experimental conditions as closely as possible. The distance between the metals was similar to that proposed for the sheep experiment.

The limitations of this preliminary experiment could be considered great, but the results obtained agreed with published tables of metal potentials (for example, Williams, 1981b), and the findings did determine placement of the metals in the sheep mandibles for the main experiment.

The posterior area of the mandible was chosen as the surgical site for implantation of the metals in the sheep. The metals were implanted as near as perpendicular as practically possible to the lower border of the mandible and parallel with the buccal and lingual cortices. It was thought that use of this area of the mandible would minimise implantation into the inferior dental canal. The results however, proved that this was not always so; in several cases it proved difficult to expose the angle of the mandible and it was noted that the bone was very thin in a bucco-lingual direction in this area. It was also noticed that while preparing the holes at the angle of the mandible, very little resistance was met, consistent with the drill entering the medullary bone. Examination of radiographs and histological sections of those cases where this had happened confirmed that the cortical bone at the angle of the mandible was very thin or non-existent (for example, refer to Fig. 4.9a and Fig. 4.12a and b).

When examining the histological sections, it was also observed that some implants had penetrated teeth and/or the inferior dental nerve.

A study of the lateral radiographs of the sheep mandibles immediately after sacrifice showed a great variance of the course of the inferior dental nerve within the bone in the area distal to the teeth. The radiodensity of the bone was also seen to vary from mandible to mandible, and from area to area within a single mandible.

A prospective implant material must undergo rigorous trials before it can be used in human clinical trials. Recommended biological tests for prospective materials have been classified by both the American Dental Association (Autian, 1974) and the Federation Dentaire Internationale (FDI) (Langeland and Cotton, 1979; Stanford, 1980). The FDI has classified dental materials into seven main categories, with subdivisions in each category. Materials for dental implants are classified as Type II Class 4 materials. A series of three levels of biological testing (Table 5.1) has been developed, and every material should undergo those tests recommended by the FDI for the class of material. Those tests recommended for implant materials are marked with an asterisk in Table 5.1. For the main experiment in this study, the bone implant usage test was used.

In the current investigation, metals with identical surface characteristics to those of the transmandibular implant were used. When the present experiment was designed, the pore size on the surface of the components of the transmandibular implant was stated to be between 1.68 μ and 2.10 μ (Bosker and van Dijk, 1983). The test metals used in the present study were prepared by the manufacturer with a similar pore size. Since then, the size of the pores has been amended to 200μ for the baseplate of the TMI, and 150 μ for the transosseous posts.

INITIAL TESTS	SECONDARY TESTS	USAGE TESTS
*Short term systemic toxicity test: oral route	*Subcutaneous implant test	*Oral mucous membrane irritation test
*Acute systemic toxicity test: intravenous route	Bone implant test	*Pulp and dentine test
Inhalation toxicity test	*Sensitization test	Pulp capping and pulpotomy test
*Haemolysis test	*Oral mucous membrane irritation test	*Endodontic usage test
*Ames' mutagenicity test		*Bone implant usage test
*Styles' cell transformation test		
*Dominant lethal test		
*In vitro cytotoxicity test (chromium release)		
*Cytotoxicity test (millipore filter)		
*Tissue culture agar overlay test		

Table 5.1 Recommended levels of biological testing. Tests for prospective implant materials are marked with an asterisk (from Stanford, 1980).

5.3 GROSS OBSERVATIONS

The condition of the skin and the soft tissues of the submandibular region and the neck immediately after sacrifice indicated good healing in all sheep in both experimental groups. The information supplied by the manufacturers of the Vicryl™ resorbable suture material (Ethicon, USA) states that the sutures should be resorbed after ten to fourteen days. This is not in agreement with the current study, where some sutures were still observed after four weeks. This latter finding is in agreement with the author's personal observations where resorbable sutures of this type have been noticed after three weeks placement in humans.

and tissue fluids is adsorbed (Baier, 1977). It is to this layer that the cells attach, not to the implant itself.

The finding of this amorphous layer in the present study is in agreement with those of Baier (1977) and Clark and Williams (1982) in relation to the formation of a thin layer of adsorbed organic material on an implant. Williams, Askill and Smith (1985) noticed that this layer was thicker in relation to copper, silver and gold (all metals in Group IB of the Periodic Table), than with metals in other groups. The removal of the implants in the present study meant that quantitation of the amorphous material was not possible.

Remodelling was seen in the cortical bone around most implants after four weeks (refer to Figs. 4.31, 4.36 and 4.43) in decalcified and undecalcified sections.

Sections from one Dentozyl® implant and one silver implant demonstrated an abrupt interface between bone and implant cavity, with lamellae perpendicular to the implant cavity (see for example Fig. 4.32), and no intervening fibrous capsule. Why there was no evidence of remodelling is unclear; one can postulate a tight interference fit of the implant, a stripping of some tissue during removal of the implant prior to processing, or the existence of bone rendered necrotic during implant cavity preparation.

Thermal injury of bone may occur during drilling procedures. It has been observed that healing following bone surgery may be delayed or even prevented if the osteocytes are severely injured by the frictional heat generated during surgical preparation (Thompson, 1958; Mazarow, 1960). Lundskog (1972) found histochemical evidence of bone death adjacent to an area heated to

50°C for 30 seconds. Eriksson et al. (1982) demonstrated that temperatures may exceed 60°C even with the use of coolants. Eriksson and Albrektsson (1983) showed that fat cell necrosis occurred up to two weeks after thermal injury, followed by repair if the injury was below a threshold value of 47°C. They also found that bone resorption after thermal injury did not occur until twenty to thirty days later. It may be that this threshold value was reached during the implantation procedure, even though a coolant was used and the drill was rotating slowly. A layer of necrotic bone may thus have formed between the implant and vital bone, and was removed with the implant. The experiment in the present study was designed to eliminate as many of the variables as possible, in accordance with the recommendations of Coleman, King and Andrade (1974). However, the control of heat produced during drilling of bone was one unavoidable variable.

Sections from the remaining Dentozyl® implants, and all platinum, palladium, gold and gold alloy implants showed evidence of bony remodelling on the cortical bone surfaces facing the implant cavities after four weeks implantation. All the bone appeared to be vital, as evidenced by the presence of osteocytes within lacunae in the bone, and osteoblasts on the surface of remodelling bone.

The extensive necrosis seen around the copper implants in the histological sections was in agreement with the gross findings of the studies of Venable et al. (1937) and McNamara and Williams (1981). In both papers it was shown that copper produced an aseptic suppuration when implanted into soft tissue. Pus was not sent for bacteriological investigation in this study, but staining of supplementary adjoining sections according to the method of Brown and Brenn (Appendix VII) failed

to detect the presence of any bacteria. The finding of a thick capsule around the copper implants after four weeks was in agreement with the findings of McNamara and Williams (1981). In the present study, the capsule did not appear to be as vascular as those described by McNamara and Williams (1981).

The responses observed around the silver implants in the present study would seem to be less extensive than those described by Pudenz (1942) and Palmer et al. (1979), and more extensive than those described by Keller et al. (1984). Palmer et al. (1979) demonstrated tooth root and bone resorption around endodontic siver points placed in monkeys. Keller et al. (1984) noticed no fibrous tissue capsule around silver when implanted into the peritoneal cavity of rats, but a decrease in cellularity adjacent to the silver was observed. Keller et al. (1984) explained that the cytotoxicity of the silver could have inhibited the tissue's attempt to sequestrate the implant, or at repair. In the present study, a fibrous tissue zone was observed around the silver implants in the medullary cavity. The fibrous zone was thicker than around all other implants except copper. Remodelling of bone was observed in relation to silver implants in cortical bone, and areas of fibrous tissue were also observed adjacent to cortical bone.

In many histological sections examined, a layer of fibrous tissue was interposed between the cortical bone and the implant or implant cavity In Zone 1 (for example, refer to Figs. 4.27 and 4.31). There are several possible explanations for the presence of this fibrous tissue;

1) scarring after surgical and thermal trauma. This would be in agreement with the findings of Lundskog (1972).

2) movement of the implant. Natiella et al. (1972), Smith (1974) and Hench and Hench (1985) all described the formation of fibrous tissue in relation to a mobile implant.
3) a loose fit of the implant at the time of placement, with resultant granulation tissue interposed between bone and the implant
4) the normal response by the body to an implanted foreign body (Williams, 1981a).

Within Zone 2 of most sections examined after four weeks implantation, a layer of connective tissue was also seen with collagen fibres running parallel to the implant cavity. This finding is in agreement with most investigators, who state that the body's response to a foreign body is that of fibrous capsule formation (for example, Homsy, 1970; Natiella et al., 1972; Williams, 1981a). Most metals were placed with a tight interference fit at the time of implantation. However, subsequent microscopic examination of histological sections revealed that little bone was present in the medullary cavity, and that fibro-adipose tissue was present. The implants could have moved in this more compressible soft tissue, but as they were unloaded, and in most instances not standing proud of the lower border of the mandible, which could have led to their attachment to the muscles of mastication, this theory is not likely. Damage due to mechanical or thermal trauma was possible, but all implants were placed with the minimum amount of force and excessive rises in temperature were hopefully avoided by the use of a coolant and a slowly rotating drill whilst preparing the implant cavities. The fibrous tissue seen in the present study was of varying thickness and density in relation to different metals. For example, around the copper and silver implants, a thick dense layer of fibrous connective tissue was observed around the implant

cavity. The fibrous tissue layer around the remaining five metals was less well-delineated, and in several sections examined appeared to blend in with the surrounding fibro-adipose tissue of the medulla (refer to Fig. 4.27). Little difference was observed between the thickness of the fibrous layer around the Dentozyl® implants when compared with the gold alloy implants. This variation in thickness of the fibrous layer could be interpreted as a function of the bioinertness of the metal; theoretically a thinner layer being observed adjacent to the more bioinert metals.

The finding of viable adipose tissue close to non-resorbable implants has been considered to be evidence of biocompatibility of implant materials (Kaminski, Shenk and Oglesby, 1977). Adipose cells are primarily storage cells with relatively few protective properties and thus could be expected to be more susceptible to damage by toxic materials. Kaminski et al. (1977) demonstrated the formation of adipose tissue adjacent to biocompatible materials six weeks after implantation in rabbits. In the implantation sites in the present study, adipose tissue was pre-existent within the medullary cavity. The observation that the adipose tissue remained viable adjacent to most implants, with the exception of copper, suggests that the remaining metals are biocompatible and non-reactive.

One feature noted in all sections from all specimens was the lack of cellularity in the fibrous tissue adjacent to the implant cavity. Although Keller et al. (1984) explained that a lack of cellularity adjacent to silver implants was due to the cytotoxic nature of the metal, their explanation does not necessarily account for the findings of the present study in relation to gold, platinum and palladium, since these metals are all known to be relatively bioinert (Zander, 1959; Caputo, 1980;

Smith, 1982). Zetner et al. (1980) did find a decrease in cell population adjacent to particulate gold in *in vitro* experiments, but this observation cannot be directly correlated with the present study. One possible explanation of the decreased cellularity adjacent to the implants is that the surface tension of the implants was outside the range required for cells to adhere to, and populate, the surface of an implant (Baier, 1977). Another explanation is that the cells were adherent to the organic layer on the implants, and were removed with them. However, the finding of only a few cells on the surfaces of the implants when examined by scanning electron microscopy indicates that this is not likely.

Very little bone was seen in the medullary cavity adjacent to the implants, although where trabeculae were pre-existent, they demonstrated areas of remodelling and bone deposition (refer to Figs 4.37 and 4.39). Meachim and Pedley (1981), when considering the tissue response at an implant site, stated that the formation of new bone could either be due to the modulation of cells within the fibroblastic and endothelial response of granulation tissue, or from osteogenic remodelling activity in pre-existing bone in the vicinity. The results of the present study would indicate that the bone around the implants was due to remodelling in pre-existing bone. Several of these trabeculae were very close to the implant cavity and the fact that they did not show any signs of active resorption at four weeks can be interpreted as a sign of biocompatibility. This suggestion is reinforced by the finding of new bone matrix on many of the trabeculae.

The current literature indicates that bone forms in direct apposition to metallic implants only in those made from titanium or its alloys (Brånemark et al., 1977; Brånemark, 1983; Hansson et al., 1983). However,

studies conducted with titanium implants have all involved the metal being placed in relatively dense medullary bone. In the present study, the medullary cavity was seen to consist mainly of fibro-adipose tissue, with comparatively little cancellous bone. Future studies could possibly include a comparison of implanted titanium with the two alloys used in the current investigation.

A consistent finding was the densely staining particulate material, in both the tissue adjacent to the implants and in vessels distant from them. The presence of particles does not necessarily mean that they have been released from the implant. For example, iron-containing particles of haemosiderin can accumulate in cells after haemorrhage (Meachim, 1975). Meachim (1975) described a method for differentiating between an exogenous origin for the particles and an endogenous haemosiderin origin. The histological sections were stained by Perls's method for ferric ions; if a positive result was obtained, the particulate material could be either endogenous haemosiderin or from exogenous implant material. A negative result excluded the presence of haemosiderin and favoured an exogenous origin for the substance. In the present study, adjoining histological sections were obtained and stained with Prussian Blue. The results were negative for haemosiderin. Therefore an exogenous source for the particles is likely.

The possible sources of the particles are firstly, corrosion products from the metal, and secondly, from the stainless steel drills used in preparation of the implant site. Hobkirk and Rusiniak (1978) demonstrated transfer of drill material, especially iron, and smaller amounts of cobalt, chromium and tungsten, into the host tissue, with less transfer occurring with older drills. Dobbs and Minski (1980), amongst others, have

demonstrated metal ion release into tissue after total hip replacement. In the current study, the debris was found in relation to all implant metals. It can be argued that its origin was from the drills, as it was found in the tissue adjacent to the implants and in the vessels. Conversely it could have been derived from corrosion of all the metals. Scanning electron microscopy of the recovered metal implants however, demonstrated corrosion only of copper and silver in both time periods (see Section 5.6). Thus it is unlikely that all the metals were the source of the particulate matter seen on histological sections. The particles could be corrosion products from the copper that had been tranferred via the bloodstream to distant sites, or by phagocytosis. This does not seem likely as the particulate matter was incorporated into the fibrous tissue around the implant. Contamination from the drill would seem most likely, and could be verified by electron microprobe analysis of the sections.

Several implants (one silver, one palladium, one gold alloy and two gold) had penetrated teeth (refer to Figs 4.40 and 4.41). Where this had happened, evidence of remineralisation was seen around the dentine chips. Around the gold alloy specimen, (Fig. 4.67) this was especially striking, as the mineralising matrix extended along the edge of the implant cavity. Although only a limited number of specimens were available for study, this finding indicated that a much more pronounced mineralised tissue response was elicited when the implant was in proximity to pulp/dentine as compared with cortical bone or medullary tissues.

Other evidence of the relative bioinertness of the implants used in this study, with the exception of copper, was the relative lack of inflammation seen around the implants. From the surgical trauma, it would

be expected that any acute inflammatory response would have subsided by four weeks after placement, and replaced with a chronic inflammatory response. With the exception of copper, no inflammation was observed in any specimen.

One feature noticed in relation to all specimens in one animal in the four week group was the presence of granulomas near the fibrous capsule. It is not clear why this occurred. Merritt and Brown (1982) described syncitial giant cells with a similar appearance to those seen in the present study, in rabbits which had been pre-sensitised to a metal later used for implantation. It may be that in the present study, the animal was sensitive to one or more of the metals. Alternatively, the sheep could have been suffering from a granulomatous disease. The carcass was not available for autopsy to eliminate this possibility. The presence of the granulomas did not appear to alter the overall tissue response to the implants.

Around two metals, gold and the gold alloy in one animal in the second experimental group, radiolucencies were detected around the implants in the cortical bone. Microscopic examination of these two specimens revealed a broad band of fibrous tissue between the implant cavity and the cortical bone, the latter demonstrating areas of remodelling and new bone formation. This was an isolated finding in response to gold and the gold alloy in only one animal. A possible explanation is the fact that the metals did not have an interference fit on insertion, and were subject to motion during the initial post-operative healing period. Natiella et al. (1972) found that the mobility of an implant increased the formation of connective tissue and in some cases caused bone resorption around it.

Within the cortical bone after thirteen weeks, Haversian systems, consistent with bone maturation were seen. This can be interpreted as a sign of the stability of the implants in the bone.

Bosker (1986) anticipated that bone would grow up to and into the superficial surface porosities of the transmandibular implant, with dense bone growing around the threads of the screws. The observation of cortical bone apparently growing in from both cortices towards the medullary cavity adjacent to a Dentozyl® implant may support the theory. However, an apparent increase in cortical width was also seen on radiographs adjacent to other metals, (see Section 5.4) and could in fact be a normal anatomical feature of the bone. The histological appearance of the bony ingrowth seen adjacent to the Dentozyl® implant was that of immature bone. The availability of pre-operative radiographs would have assisted in determining whether this feature was an ingrowth of bone in response to the metal, or whether it was pre-existent

Although an apparent area of direct bone to metal contact was observed in some sections, bone was not seen to be situated in the pores on the surface. This finding is in agreement with the findings of Cameron et al. (1976), who found that surface porosities of an implant needed to be greater than 100μ to permit bony ingrowth, and a pore size of 150μ was necessary to allow for Haversian system remodelling. Since the design of the present study, the size of the pores of the surface of the transmandibular implant have been altered to 150μ and 200μ (Bosker, 1986). This greater roughness has probably been provided to enhance retention, in agreement with the findings of Thomas (1985).

5.6 SCANNING ELECTRON MICROSCOPY AND ELECTRON MICROPROBE ANALYSIS

The EMPA results reported here are annotated spectral plots recorded from various components of the specimens. Due to complex interactions in the specimens, the element peaks cannot be correlated to abundance by relative peak height. The spectra give information on the presence of elements in the material examined. Many of the surface deposits examined are of micron size. The electron beam penetrates these and interacts with the underlying materials. As a result, most recorded spectra contain some X-ray component recorded from the metal implant in addition to the signal from the surface deposit. Organic coatings were recognised by a lack of recorded elements other than constituents of the implant, a lessening of the count rate compared with adjacent areas on the implants, and a darkening of the area visible in SEM examination.

The control metals stored in formalin and decalcifying solutions did not show any different surface characteristics from the control metals kept in air. It was therefore concluded that any surface deposits on the experimental samples were from the implantation.

The control metals showed a superficially porous structure in agreement with that stated by Bosker and van Dijk (1983), namely a pore size of between 1.68μ and 2.10μ. This has since been altered to 150μ for the posts of the implant, and 200μ for the baseplate and cortical screws (Bosker, 1986). Occasional particles were seen on the surface of the metals; EMPA recorded the presence of aluminium. The analyser used (Tracor Northern TN 5500 model EDS System) records elements only with an atomic number greater than eleven. It can therefore be assumed that the lodged particles are pieces of alumina (Al_2O_3) remaining from surface preparation.

A problem encountered in interpretation of the observations of scanning electron microscopy was related to the method of preparation of the specimens. When designing the experiment, it was planned to examine the surface of the metal for evidence of corrosion. It was therefore decided to air dry the metals after storage in alcohol. Oron and Alter (1984), studying stainless steel implants for surface corrosion boiled the implants in distilled water for sixty minutes to remove all adherent organic matter. In order to visualise biological tissues in the scanning electron microscope, it is generally accepted that the water must be removed after fixation of the organic material, in order to avoid freezing due to rapid evaporation of water in the evacuated specimen chamber. Fixation is unnecessary for metals and may lead to artifacts and corrosion (McNamara and Williams, 1982b). The main problem in the present study was therefore the removal of water from the tissues without introducing artifacts. This can be achieved by slow evaporation in air, or by replacing the water with a volatile solvent and allowing this to evaporate. Both methods will create some distortion of organic matter, and critical point drying is generally favoured.

On all implants examined at both time periods, a thin coating, interpreted as an organic layer, was visible over the surface of the metal, evidenced by areas of shadow on the photographic image, An organic origin for this layer can be assumed due to the incomplete electron beam penetration. Its presence is in agreement with the findings of Baier (1977) and Clark and Williams (1982) who reported that a thin layer of material is adsorbed to the surface of an implant after placement.

The appearance of the copper implants after four weeks was that of an irregular granular surface containing calcium, phosphorus and chlorine in addition to copper.

McNamara and Williams (1982a) studied the surface of copper discs implanted intramuscularly in rats and described a surface similar to that seen in the present study. McNamara and Williams (1982a) described the surface as being cellular. In the present study, a cellular nature of the surface cannot be excluded, but the findings of the EMPA are more suggestive of a crystalline nature of the surface; in particular the presence of copper chloride, derived from corrosion of the copper in the chloride-rich tissue fliud.

The Dentozyl® implants were covered with an organic film after four weeks implantation. Spherical objects with diameters of between 3μ and 5μ were present on the surface. Although two types of surface characteristics were observed, both types of objects recorded the presence of calcium and phosphorus when analysed by EMPA. Calcium and phosphorus are the main inorganic constituents of hydroxyapatite, and it could be postulated that these objects are crystals of hydroxy-apatite forming on the surface of the implants. Whilst those objects with loosely packed surface arrangements are in agreement with the observations of Lindskog (personal communication) regarding early calcified tissue formation, the objects with a more closely packed surface could be cells demonstrating calcification consequent to the inflammatory responses resulting from surgical trauma.

Stallard et al. (1975) described a similar type of structure with a honeycomb appearance on the surface of vitreous carbon implants to those seen in the present study. Stallard et al. (1975) stated that they were keratinised cells without cytoplasmic extensions. It is unlikely that the structures seen in the present study are keratinised cells, although it is conceded that they could be cellular in origin, despite their small size.

Further studies using different methods of implant preparation would assist in differentiation of the calcium and phosphorus-containing bodies observed in this study.

The apparent lack of cells adherent to the organic coating on the surface of the metals was not unexpected. A connective tissue zone was seen around all the implant cavities in both time periods using optical microscopy.

The original surface morphology of the silver implant was less clear than that of Dentozyl® after four weeks. This could be due to corrosion of the metal, a thicker organic coating, or a combination of the two factors. Objects were again observed on the surface of the metal; EMPA of the subspherical deposits recorded the presence of silver, chlorine, and phosphorus, and that of the equant crystals chlorine, sulphur and silver. These findings are more consistent with a crystalline nature, possibly from the corrosion of the silver in the tissue fluid, than an organic origin. The findings of the present study are in agreement with those of Seltzer et al. (1972), who observed corrosion of endodontic silver points and descibed surface agglomerations similar to those seen in the present study. X-ray diffraction in the study of Seltzer et al. (1972) recorded the presence of sulphides and sulphates and other similar reaction products.

Apart from a thin organic coating, little else was noted on the surface of the other metals (platinum, palladium, gold alloy and gold) when examined by SEM. On one platinum implant, a cell-like structure was observed, with several extensions from a main body. Occasional irregular deposits were seen on all other implants after four weeks implantation. They were all noticed to contain calcium and phosphorus when subjected to EMPA.

Several workers have described protruberances containing calcium and phosphorus on recovered implants (for example, Morse, Barnett and Maggio, 1972). Bosker (1986) noticed that surface accumulations on a screw removed from a transmandibular implant in a human contained calcium and phosphorus, a finding which he attributed to the bone adhering to the implant with such a force that when the screw was removed, the bone fractured rather than the bone/metal interface. This theory is unlikely in view of the current findings when isolated clusters of the calcium/phosphorus containing material were found.

The results obtained after thirteen weeks implantation were similar to those after four weeks implantation in that the copper exhibited marked corrosion and organic coatings were seen on the remaining six metals. The surface of the silver implants demonstrated varying surface morphology (see Fig. 4.91) with irregular granular deposits in places and the original surface morphology in other areas. This appearance may indicate a differential corrosion occurring.

Several authors have noticed the presence of iron in EMPA studies of recovered metallic implants. Morse et al. (1972) considered that the iron could have originated from the drill, from haemorrhage, or a normal tissue component. Seltzer et al. (1982) also detected iron, but did not postulate as to its origin, whereas Bosker (1986) stated the origin to be from blood. The present study did not detect the presence of iron on any implant.

No deposits containing calcium and phosphorus were detected after thirteen weeks. The reason for this is unclear.

Dentozyl® did not appear to corrode in the present study, even though it is known that higher silver content alloys exhibit a decreased corrosion resistance in a chloride environment (Sarkar, Juys and Stanford, 1979a,b). The implantation times in the present study are relatively short, and further experiments could be performed with longer implantation times to determine whether or not Dentozyl® exhibits long term corrosion resistance.

The results of the quantitative microanalysis are in agreement with the manufacturer's stated compositions of the gold alloy and Dentozyl®. The analyser was not programmed to record the presence of zinc and ruthenium. At the time of the experiment, it was thought that the Dentozyl® contained only gold, silver, palladium. platinum and copper. Thus the percentage total of the components recorded in the present study was less than 100.

CONCLUSIONS

The conclusions drawn from this study are:

1. With the exception of copper, all implanted metals appeared to be well tolerated by the tissues, as evidenced by a lack of inflammation, fibrous connective tissue encapsulation and at least focal bone reactivity in the area of the implants. The observed responses of the tissues to copper, namely an intense inflammatory reaction and abscess formation are in agreement with the findings of Venable et al. (1937) and those of McNamara and Williams (1982b). The responses of the tissues to the silver implants in the present study were not as marked as those shown by Pudenz (1942) or by Keller, Marshall and Kaminski (1984).

2. The remaining metals; gold, platinum and palladium, and the two alloys all demonstrated evidence of biotolerance as evidenced by a lack of inflammation, and the formation of fibrous connective tissue around the implants. A fibrous capsule formed in the medullary portion of the mandible around all of these metals; however, it was thinner and less well-defined than around the copper and silver. These findings are in agreement with those of Zander (1959) and Smith (1982) in relation to gold, and those of Nagem-Filho et al. (1975) in relation to the gold alloy.

3. The cortical bone demonstrated evidence of at least focal remodelling around all implants. With the exception of copper, most specimens exhibited some evidence of close bone/metal apposition in both time periods, but the general pattern observed was that of a layer of fibrous connective tissue of variable

thickness interposed between the implant and the cortical bone.

4. Bone did not tend to form close to the implants in the medullary portion of the mandible unless bony trabeculae were pre-existent adjacent to the implants.

5. Only copper and silver exhibited corrosion when examined by scanning electron microscopy. The remaining five metals appeared to be corrosion resistant. These findings are in agreement with those of Pudenz (1942), Seltzer et al. (1972) and McNamara and Williams (1982a).

6. The sheep was a relatively easy animal to handle with respect to anaesthesia and surgery, with no special techniques or instruments required. It is suggested that the sheep could be used as an alternative animal to monkeys and dogs for implantation studies. The particular area of the mandible of the sheep chosen for this study was in retrospect not ideal in that very little cancellous bone existed; the medullary contents were mainly fibro-adipose tissue. It is suggested that future studies should perhaps concentrate on implantation only in cortical bone.

7. Under the implantation conditions used in this study, there would appear to be no difference in the tissue responses to the Dentozyl® and the gold alloy.

IA								VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	INERT GASES
1 H 1.0079	IIA																	2 He 4.0026
3 Li 6.941	4 Be 9.01218												5 B 10.81	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.998403	10 Ne 20.179
11 Na 22.98977	12 Mg 24.305	IIIB	IVB	VB	VIB	VIIB		VIII			IB	IIB	13 Al 26.98154	14 Si 28.0855	15 P 30.97376	16 S 32.06	17 Cl 35.453	18 Ar 39.948
19 K 39.0983	20 Ca 40.08	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.69	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80	
37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.22	41 Nb 92.9064	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.42	47 Ag 107.868	48 Cd 112.41	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9045	54 Xe 131.29	
55 Cs 132.9054	56 Ba 137.33	57 *La 138.9055	72 Hf 178.49	73 Ta 180.9479	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.9665	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.9804	84 Po (209)	85 At (210)	86 Rn (222)	
87 Fr (223)	88 Ra 226.0254	89 †Ac 227.0278																

() Numbers in parentheses are mass numbers of most stable or most common isotope.
Atomic weights corrected to conform to the 1979 values IUPAC.

*LANTHANUM SERIES

58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.9254	66 Dy 162.50	67 Ho 164.9304	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.967

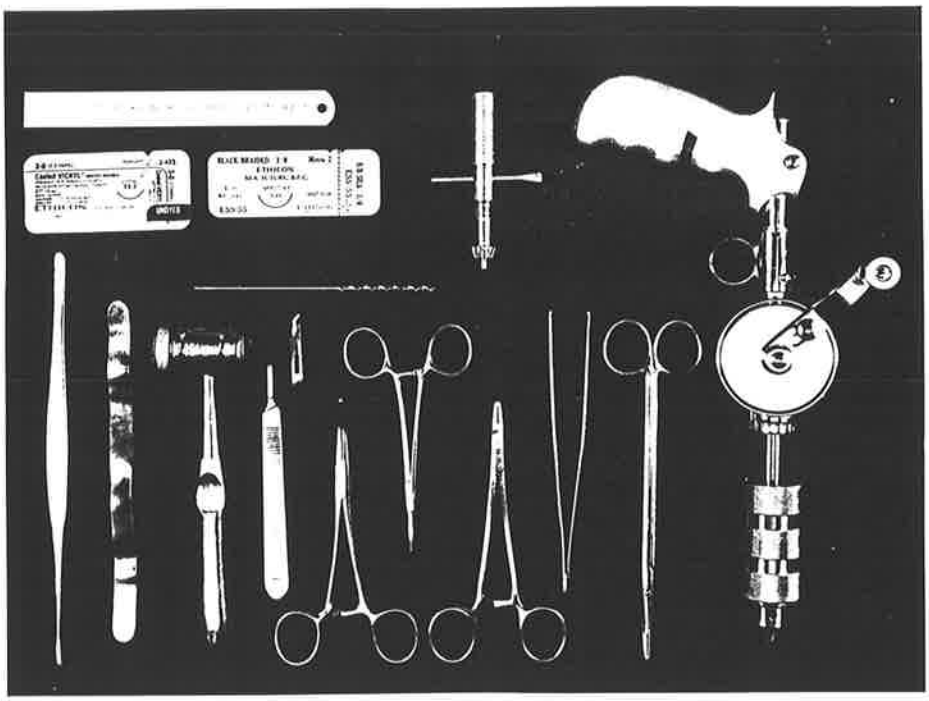
†ACTINIUM SERIES

90 Th 232.0381	91 Pa 231.0359	92 U 238.0389	93 Np 237.0482	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

	Calomel	Platinum	Palladium	Copper	Dentozyl®	Gold alloy	Gold	Silver
Platinum	-0.083	—	0.033	0.269	0.202	0.094	0.107	0.142
Palladium	-0.047	-0.032	—	0.234	0.223	0.063	0.100	0.130
Copper	0.101	-0.264	-0.234	—	0.008	-0.170	-0.145	-0.114
Dentozyl®	0.055	-0.197	-0.240	-0.005	—	-0.196	-0.078	-0.042
Gold alloy	0.028	-0.084	-0.068	0.174	0.186	—	0.028	0.057
Gold	0.042	-0.107	-0.100	0.146	0.079	-0.028	—	0.030
Silver	0.052	-0.141	-0.131	0.115	0.040	-0.059	-0.031	—

Table showing the results of the preliminary experiment to determine the potentials of the metals. All values are expressed in millivolts.

APPENDIX III INSTRUMENTS USED IN THE OPERATIVE PROCEDURE OF THE MAIN EXPERIMENT.



1. Howarth periosteal elevator
2. Malleable retractor
3. Surgical mallet
4. No. 3 scalpel handle
5. No. 15 scalpel blade
6. Curved artery clips
7. Mayo needle holder
8. Gillies' tissue forceps
9. Metzebaum scissors
10. Orthopaedic hand drill and chuck
11. Ruler
12. 3-0 resorbable (Vicryl™) suture
13. 3-0 black silk suture

APPENDIX IV TISSUE FIXATION.

Mandibles were fixed in 10% neutral buffered formalin after sacrifice. Adequate time was allowed for infiltration of the fixative before the mandibles were cut into blocks each containing one implant.

The recipe for the formalin solution is as follows:

Formalin	500ml
Tap water	4,500ml
Acid sodium phosphate monohydrate	20g
Anhydrous disodium phosphate	32g

APPENDIX V DOUBLE EMBEDDING PROCEDURE FOR DECALCIFIED SECTIONS.

Decalcified specimens were processed in the following reagents:

1.	70% alcohol	overnight
2.	Absolute alcohol	2 hours
3.	Absolute alcohol	2 hours
4.	Absolute alcohol	2 hours
5.	Absolute alcohol	2 hours
6.	Methyl salicylate and absolute alcohol	overnight
7.	Methyl salicylate	8 hours
8.	Methyl salicylate	8 hours
9.	Methyl salicylate and 1% celloidin	2 days
10.	Methyl salicylate and wax*	1 hour
11.	Wax*	2 hours
12.	Wax*	2 hours
13.	Wax*	2 hours
14.	Wax* under vacuum	1 hour

The specimens were then blocked in molds.

* Paraplast® Plus; Monoject Scientific, St. Louis, USA.

APPENDIX VI PROFORMA USED FOR THE ASSESSMENT OF DECALCIFIED SECTIONS.

Slide No.

Time period: 4/13 weeks

	CORTICAL	CANCELLOUS
INFLAMMATION		
FIBROUS CAPSULE		
BONE/METAL CONTACT		

COMMENTS

Inflammation	-	nil
	+	up to five foci
	++	5 - 10 foci
	+++	more than ten foci
	++++	diffuse inflammation
Fibrous capsule	-	not present
	+	intermittent
	++	widespread
Bone/metal contact	-	not present
	+	present but incomplete
	++	present and complete

APPENDIX VII THE STAINING TECHNIQUES USED FOR THE DECALCIFIED AND UNDECALCIFIED MATERIAL.

1. HAEMATOXYLIN AND EOSIN STAIN

Method

1.	Xylol	2 - 5 mins
2.	Xylol	2 - 5 mins
3.	Absolute alcohol	2 - 5 mins
4.	Absolute alcohol	2 - 5 mins
5.	Dip in tap water	
6.	Harris' haematoxylin	3 - 5 mins
7.	Tap water	5 mins
8.	0.5% to 1.0% hydrochloric acid in 70% alcohol	30 secs
9.	Running tap water	10 mins
10.	Eosin	45 secs
11.	Absolute alcohol	1 min
12.	Absolute alcohol	1 min
13.	Xylol	1 min
14.	Xylol	1 min

The sections are then mounted in Depex.

Results

Nuclei	blue to blue/black
Basophilic cytoplasm	purplish
Red blood cells	bright orange/red
Decalcified bone matrix	deep pink
Collagen and osteoid tissue	light pink

2. GOMORI'S ONE STEP TRICHROME STAIN

Method

1.	Harris' haemalum (to stain nuclei)	5 mins
2.	Tap water	2 mins
3.	Distilled water	rinse
4.	Chromotrope-green mixture	5 - 20 mins
5.	0.2% acetic acid	rinse
6.	Absolute alcohol	2 mins
7.	Xylene	1 min
8.	Xylene	1 min

The sections are then mounted in the usual manner.

Results

Nuclei	grey/blue
Collagen	green
Cytoplasm, red blood cells, fibrin	red

3. PERLS' PRUSSIAN BLUE STAIN FOR HAEMOSIDERIN

Method

1.	Distilled water	rinse well
2.	2% potassium ferrocyanide/2% 2% hydrochloric acid (50:50)	20 - 30 mins
3.	Distilled water	rinse well
4.	Counterstain with eosin	5 mins
5.	Absolute alcohol	1 min
6.	Absolute alcohol	1 min
7.	Xylene	1 min
8.	Xylene	1 min

The sections are then mounted in the usual manner.

The ferric iron combines with potassium ferrocyanide to form the insoluble Prussian blue precipitate as follows:

$$4FeCl_3 + 3K_4Fe(CN)_6 = Fe_4[Fe(CN)_6]_3 + 12KCl$$

Results

Haemosiderin and ferric salts	deep blue
Tissues and nuclei	red
Other pigments	normal colours

4. BROWN AND BRENN STAIN FOR BACTERIA

Method

1.	Crystal violet solution/ sodium bicarbonate solution (4:1)	1 min
2.	Tap water	rinse
3.	Gram's iodine solution	1 min
4.	Distilled water	rinse
5.	Decolourise with ether-acetone mixture	
6.	Basic fuchsin	1 min
7.	Distilled water	rinse
8.	Picric acid-acetone solution	until yellowish
9.	Acetone	rinse
10.	Xylene	1 min
11.	Xylene	1 min

The sections are then mounted in the usual manner.

Results

Gram positive bacteria	blue
Gram negative bacteria	red
Filaments of Nocardia and Actinomyces	blue
Nuclei	red
Other tissue elements	yellow

5. MODIFIED TRICHROME STAIN FOR UNDECALCIFIED SECTIONS (UNIVERSITY OF ADELAIDE, 1986)

Recipe

Red stain	Chromotrope 2R	0.6g
	Phosphotungstic acid	0.6g
	Glacial acetic acid	1ml
	Distilled water	100ml
Green stain	Fast green FCF	0.3g
	Phosphotungstic acid	0.6g
	Glacial acetic acid	1ml
	Distilled water	100ml

Method

1.	Place dry Araldite sections in red stain	overnight
2.	Water	wash well
3.	Distilled water	rinse
4.	Fast green FCF solution	until desired colour
5.	70% alcohol	rinse
6.	Absolute alcohol	1 min
7.	Absolute alcohol	1 min
8.	Xylene	1 min
9.	Xylene	1 min

The sections were then mounted with liquid paraffin under standard glass coverslips.

Results

Bone and calcified tissue	green
Soft tissue	red

APPENDIX VIII EMBEDDING PROCEDURE FOR UNDECALCIFIED SECTIONS.

Undecalcified specimens were processed in the following reagents:

1.	70% alcohol	24 hours
2.	80% alcohol	24 hours
3.	95% alcohol	24 hours
4.	Absolute alcohol	24 hours
5.	Absolute alcohol/Cu_2SO_4	72 hours
6.	Absolute alcohol/Cu_2SO_4	72 hours
7.	Xylene	72 hours
8.	Xylene	96 hours
9.	Xylene	96 hours
10.	Absolute alcohol/Cu_2SO_4	24 hours
11.	Absolute alcohol/Cu_2SO_4	24 hours
12.	Acetone	24 hours
13.	Acetone	72 hours
14.	Acetone	24 hours
15.	Resin*/alcohol (50:50)	72 hours
16.	Resin*	72 hours
17.	Resin*	72 hours
18.	Resin* @ 60°C	48 hours

* Araldite-D® resin; Ciba-Geigy Australia Pty. Ltd.

APPENDIX IX RESULTS OF THE QUANTITATIVE ANALYSIS OF THE GOLD ALLOY AND DENTOZYL.

GOLD ALLOY	Gold	72.54 ± 0.79*
	Platinum	4.44 ± 0.15
	Silver	11.31 ± 0.19
	Copper	12.87 ± 0.20
		101.16%

DENTOZYL®	Gold	10.82 ± 0.10*
	Palladium	21.42 ± 0.31
	Platinum	9.36 ± 0.82
	Silver	53.93 ± 0.29
	Copper	2.39 ± 0.23
		98.33%†

A total of six readings from each of two samples of the metals was recorded.

* The percentage of gold has been corrected from a high reading due to the proximity of the emission spectrum of platinum.
The actual recorded value for the gold content in the gold alloy was 72.27± 0.79, and 10.80± 0.11 for the Dentozyl®.

† Quantitation of ruthenium and zinc was not performed, as at the time of the experiment it was believed thatDentozyl® contained only those elements recorded above. Therefore the total composition recorded is less than 100%.

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