BONE HEALING ADJACENT TO TANTALUM IMPLANTS

Richard E. Morris, D.D.S.

This paper submitted in partial fulfillment of the requirements for a Certificate in Orthodontics, University of Oregon Dental School.

June 10, 1972

ACKNOWLEDGMENT

The author wishes to thank Dr. Ernest H. Hixon, Dr. Douglas L. Buck, Mr. Richard Tacke, and Dr. Robert Quinton-Cox for their assistance in the project.

TABLE OF CONTENTS

INTRODUCTION

Beginning in 1965, radiographic markers made of the metal tantalum were implanted into patients undergoing orthodontic treatment at the University of Oregon.[1] The implants were utilized in an attempt to increase reliability of cephalometric radiographic tracings made during the course of orthodontic treatment. Patients were implanted after the manner of Bjork[2] into maxillary and mandibular alveolar bone on the side of the patient which was closest to the film cassette during exposure of radiographs. Implants from subsequent radiographs during treatment were superimposed onto the implants in the original radiograph. In this way, it was hoped that estimates of spatial movement of various parts of the skull and teeth, and also appositional growth of individual bones could be made more accurately than when no implants were used.

Measurement error was estimated by Bjork[3] to be within the range of ± 0.5 mm. when double determinations on radiographs were made using the implanting technique. This measurement error is the result of many factors. Among these factors are the measurement error of the investigator and his equipment and the variations in exposure and processing of films.[1] Another major source of error results from differences in position of the patient in the cephalostat upon exposure of subsequent films. In order to minimize this problem, Sorensen, Cruikshank, and Nixon[4] have proposed a method whereby the positions of three implants are located on an x, y, and z axis. Subsequent films are re-oriented by locating the position of the group of implants relative to its original position. Thus, errors in patient positioning which would make superimposition of subsequent films

unreliable when using a two-dimensional scale are rendered of no significance when the third dimension is taken into consideration. It is of vital importance in this latter technique that the implants remain in exactly the same place within the bone in which they are placed.

However, a problem arises in a few patients in that the implants have been found to "tumble" or move in relation to one another. In these cases, subsequent cephalometric radiographs of the implants cannot be perfectly re-oriented to the beginning treatment film. Bjork[3] also notices this phenomenon in some of his radiographs and ascribed it to three possible causes: 1-Active tooth eruption; 2-Implants not placed deep enough, thus allowing periosteum to drag on the implant; 3-An electrolytic effect of the metal which stimulates fibroblastic activity.

A histologic study appeared to be a logical method for ascertaining what is going on in the tissues next to the implants. A search of the literature revealed that no such studies have been published which assess this problem in relation to tantalum implants. Therefore, it was decided to use microscopic tissue examination techniques for the purpose of determining if any type of reaction could be found in the tissues surrounding tantalum implants which could account for spatial movement of the implants in some human patients.

The study was designed to describe the healing process around tantalum implants in alveolar bone of a dog for a period of eight weeks.

REVIEW OF LITERATURE

For centuries, man has been placing metals into living tissues for medical and scientific purposes. It is recorded that Petronius[5] as early as 1565 fabricated and placed a gold plate to replace a cleft palate. Since that time, various metals have been used by men for prosthetic replacement of missing or damaged parts of human bodies and for markers in bone to discover the manner in which osseous tissue grows. More recently, metal markers have been used in conjunction with radiographs to study how the facial complex grows. It is primarily the use of metal markers in studies of facial growth and orthodontic tooth movement with which this study is concerned. However, a review of the literature concerning use of metal in tissues throughout history is in order. Such a study fosters an appreciation of the long struggle by man to find suitable metals and techniques for placement in the human body.

Recorded uses of metals in the body in early history are rare. Notable experimenters include Fabricus, who in 1647[6] first reported the use of sutures made of iron wire. Later, Steven Hales (1727)[7] was credited with the first use of metal markers for studies of bone growth. He pierced two small holes $\frac{1}{2}$ inch apart in the tibia of a growing chicken with a sharp pointed iron and placed metal markers. Two months later, Hales observed the markers and found them still $\frac{1}{2}$ inch apart, despite growth in length of the tibia. This was the first evidence for appositional growth of bone.

Duhamel (1743)[8] essentially expanded Hale's experiment when he used silver stylets placed at regular intervals throughout the length of long

bones in the growing pigeon and dog. After a period of growth, Duhamel measured the silver markers again. His conclusions agreed with Hales, but he did note some increases in distance between markers in the middle portion of long bones.

The famous scientist John Hunter (1770)[9] became interested in bone growth and used a growing pig tibia with carefully placed and measured lead shot as markers. He also fed madder to the animals to mark the new bone growth and confirm what the metal markers disclosed. Hunter concluded that apposition was the manner in which bone grows, but as with Duhamel, he reported some separation of his metal markers. Hunter explained his results with the belief that there was unequal pull of periosteum on the markers at various points along the length of long bones. He thought that the firm attachment of periosteum at the epiphyseal line caused a sliding of the periosteum along the mid-portion of long bones and hence a drag on his shallowly placed lead shot.

Medical use of metals in the body began to grow in the eighteenth century after Icart (1775)[6] reported use of iron wire to approximate a fractured bone. Later, an extensive experiment on 21 dogs was performed by Levert (1829)[10] to find a suitable material for suturing aneurysms of blood vessels. He placed wires of various materials around the carotid arteries of dogs and killed the animals after various periods of time. He reported results of his gross examination of the implanted metals. The metals used included gold, silver, lead, and platinum. Levert found platinum to be the best tolerated and concluded that "tying of arteries with lead and other metals is free from danger."

Burke[11] identifies Langenbeck (1850) as the first to report a technique of nailing fractures to the femoral neck in humans. Later

Flourens[12] and Ollier[13] in 1861, used silver balls and lead shot, respectively, in rabbits to study bone growth. Holes were drilled and wire rings placed at the anterior and posterior borders of the ramus of a growing pig by Humphery in 1864.[14] Sacrifice of the animal showed the anterior ring sloughed in soft tissue and the posterior ring more deeply imbedded in bone. This demonstrated the apposition, resorption pattern which occurred in mandibular growth.

In 1883, Joseph Lister[15] reported on use of 1/16 inch silver wire sutures and aseptic technique in repairing bone fractures. The advent of aseptic surgery greatly increased the successes of surgeons using metal implants.[16]

Kitteredge (1891)[17] reported a successful reduction of a fractured patella using a galvanized iron staple. He noted that next time he would rather use a copper or silver staple to minimize corrosion of his implant.

Lane in 1905,[18] started a controversy which lasted at least a decade. His report of use of a steel plate to bind fractured bone segments in two cases caused a rush by surgeons to implant steel in their patients. Lane's radiographs showed nice bone apposition, but many surgeons experienced disappointing failures with the steel plate. In 1914, the American Journal of Surgery published a series of articles by surgeons[19,20,21] showing failures with the "Lane Plate," and admonitions to use metal implants in fracture reduction only as a last resort. This was despite a very energetic experiment by Groves[22] in which many different types of implants were implanted in a large group of animals. He concluded that nickel-plated steel has no irritating effects on tissues, and that aseptic foreign bodies are well tolerated by tissues.

Mann[23] imbedded steel screws in dogs and found they healed with only slight rarefactions in radiographs at four weeks. Trout[24] disagreed with Mann and showed arrest of bone growth with steel screws imbedded in young rabbits.

Lane continued to defend metal implantation by blaming other surgeon's failures with his plate onto poor and septic surgical techniques.

New tools were brought into use in the search for safe metals to implant in the human body. In 1908, the microscope was utilized in studying what happened in tissue surrounding metal implants. In that year, Von Baeyer[25] observed that metal particles were set free from implants and could be identified in surrounding tissue.

Radiographs were first used in conjunction with metal markers in bone studies by Dubreuil in 1913.[26]

Zierold[6] undertook a massive experiment with metal implants in 63 dogs in 1924. Holes were drilled in the tibia, femur, ribs, and skulls of dogs. Into these were placed implants of gold, copper, nickel, aluminum, bronze, magnesium, aluminum, high-carbon steel, low-carbon steel, lead, iron, and stellite (chrome-cobalt). After sacrifice of the animals, histologic, radiographic, and gross examination of the tissues was performed. Zierold's well-structured study concluded that "normal variation in the reaction of living tissues is great." However, gold, aluminum, and the chrome-cobalt alloy were readily tolerated by bone, became encapsulated, and caused little hindrance to the repair process. Steel was found to be the least suitable of all for bone prosthesis.

The seemingly equivocal results of Hunter and Duhamel two centuries before, prompted Haas in 1926,[27] to repeat their studies with more sophistication. Using silver implants in rabbits and dogs, and

utilizing radiographs, Haas finally dispelled forever the ghost of interstitial growth of long bones.

Gatewood and Mullen (1927)[28] again confirmed that no longitudinal growth occurs in the diaphysis of long bones. They placed lead shot one centimeter apart throughout the length of long bones in the rabbit.

The influences of discs of various metals on growth of osteoblasts and fibroblasts in tissue culture was studied by Menegaux, Odiette, and Moyse in 1934.[29] They concluded that some metals retarded growth of osteoblasts and that the toxicity of metals was the chief factor involved. Chrome-nickel steel alloys were found not to inhibit growth of tissue cultures.

Bisgard and Bisgard (1934)[30] used steel markers and radiographs on the humerus and ulna of goats to show that new bone is deposited between the end of the diaphysis and the epiphyseal plate and also between the epiphyseal plate and articular cartilage.

A survey was made by Northfield[31] into the success of metals which had been implanted into patients in the treatment of fractured bones. The 77 cases he followed showed that silver was less prone to failure when used to splint bone fractures than was steel.

Jones[32] placed tacks of vanadium steel, nickel-free rustless steel, and two types of chrome-nickel rustless steels into four dogs. The latter two steels were shown by histology to be tolerated the best. Jones also placed the four metals in Ringer's Solution, after weighing, and then reweighed them after 30-75 days. It was found that the chrome-nickel steels did not corrode and lose weight as did the other steels. Therefore, Jones concluded that the reaction of bone to metal is linked to metallic corrosion.

Venable and Stuck[33] performed a very noteworthy experiment using 50 dogs with screws of various metals implanted in the radii of the animals. They concluded from radiographs, histology, and gross observation that pure metals are the least destructive to bone. The reactions in the tissues which they observed were claimed to be purely chemical in nature. Metals of different types in the same animal, or alloys of different metals cause electrolytic reactions and formation of irritating metallic salt solutions in body fluids, they said.

A method for studying sutural growth was advanced by Gudden in 1942.[34] He drilled 4 mm. diameter depressions in the skulls of growing dogs and into these placed bone wax mixed with carbon. The dogs were later killed and the increase in distance between the bone inlays was measured.

In 1940, Bunnel[35] was the first to mention use of a new metal, tantalum, for implantation. He also listed as possible causes for foreign body reaction to metals: chemical, allergic, and electro-chemical phenomenon.

The use of tantalum as suture material was advanced by Burke in 1940.[36] He claimed it to be far superior to any other suture material then in use. He found no reaction from tissues whatsoever and no scar was left in subcutaneous tissue. Burke also placed tantalum wire in Ringer's Solution at body temperature for three months and found no change in weight or appearance of the metal. In addition, he placed tantalum screws into bones in dogs and rabbits and found normal healing occurred and that it was difficult to unscrew the implants.

Implantations of tantalum onto bone were reported by Carney in 1942.[37] He weighed tantalum plates and screws and applied them to the tibia of dogs. These remained in place 30-108 days and then were removed and

reweighed. It was found that the metal had lost negligible weight in vivo. Histological results showed a thin film of fibroblasts surrounding the metal plates. No edema or inflammatory changes were observed. Carney concluded that "the metal is well tolerated by tissues."

Bernier[38] used a new alloy, vitallium, in 1943, in bone studies. He reported bone to be in direct contact with vitallium screws which were screwed into cuspid extraction sites in monkeys.

Venable in 1943,[39] was able to state that only three metals were safe for surgically implanting in the human body: 18-8 SMO stainless steel, tantalum, and vitallium. He reaffirmed his belief that to be useful in the human body a metal must be free of electroactivity in body fluids.

The correlation between "anodic back EMF" and weight loss due to corrosion of metals was studied by Clark and Hickman.[40] They concluded that anodic back EMF may be correlated to behavior of metals in tissues. They also listed as the two main theories of tissue reaction to metals: electrochemical and toxicity.

Nichols[41] placed six vitallium implants in four dogs, left them for 2-5 months, then observed histologically the tissue next to the implants. He found a layer of dense connective tissue formed between the vitallium and bone as a result of osteoclasis and reorganization of bone tissue.

Bjork in 1955,[2] first reported his very important work utilizing tantalum implants in the jaws of growing children to study the growth of growth of the face. His descriptions of maxillary and mandibular growth and of changes in tooth positions remains the most definitive of any yet reported. By 1963, Bjork[3] could report on 12 years of study of 110 children. His cephalometric tracing showing the extreme variations in

mandibular growth have become classic.

Rapid mechanical palatal expansion was studied by Krebs in 1959,[42] with the aid of vitallium implants placed on both sides of the maxilla of nine patients requiring this procedure. Headplates were then used to measure the increase in distance between the implants as treatment progressed.

Cohen in 1961,[43] found that surface finish made a difference in the adhesion of bone to implants. He used chrome-cobalt screws placed into two dogs and measured resistance to removal with a torque wrench. A sand-blasted finish gave greater resistance to unscrewing than did electrolytically polished surfaces. However, the histologic picture was similar adjacent to both surface finishes on the metals.

Bjork in 1963,[3] briefly mentioned a six year study comparing tantalum and chrome-cobalt markers for tissue tolerance. His radiographic study showed less movements of tantalum implants after placement in human facial bones.

Rapid palatal expansion of five patients with surgically repaired complete clefts was studied by Isaacson.[44] He used modified silver endodontic cones as implants. These were placed on both sides of the zygomatic process and on both sides of the alveolus adjacent to the maxillary first molar. He demonstrated expansion of both "basal" and alveolar bone in 4-12 year olds, but a 22 year old patient exhibited only tooth expansion.

Coccare[45] used tantalum implants to study changes of points A and B in two denture patients after extraction of the anterior teeth. He found that there was a distal movement of both these points but that point A was the more stable of the two.

In 1967, Lang[46] proposed a four-point system of grading implants for suitability for use in tissues. The thickness of the pseudomembrane of fibrous connective tissue around the implants was used for criteria.

Held[47] placed various materials in contact with rabbit tibias and observed the implants histologically at 46 to 223 days. He used 18 carat gold platimum alloy, 20 carat gold, 18 carat gold, vitallium, tantalum, and acrylic as implants. He concluded that acrylic and tantalum caused the least hyperplastic bone formation.

Kaminski[48] used stainless steel discs placed in 20 rabbit mandibles and calvariums to check for differences of reactions in various sites of implantation. He found less reaction of the calvarium to the discs than the mandible exhibited. The mandible showed areas of resorption and stimulation of new bone growth, whereas the calvarium did not. He also found much variation in thickness of the fibrous membrane surrounding the discs. He concluded that you cannot use this method as a criteria for evaluating tissue response.

Sarnat[49] used dental amalgam placed into undercut preparations made into the facial bones of rabbits and Hampshire pigs.

MATERIALS AND METHODS

A perusal of bone implant literature revealed that the dog[6,8,10,16,27,32,33,34,37] has been a successful experimental animal for bone studies in the past. Therefore, it was decided to use this animal for the project.

In the design of the experiment, one animal was used to eliminate variability between animals. The dog selected was an adult cocker spaniel weighing 24 pounds. The animal was fed a regular laboratory diet except for the two days after each implanting procedure when a soft diet was given.

For the maxillary implants, wire of 90% tantalum and 10% tungsten* was used. This is identical to that which has been used previously by Bjork[2,3,4] and at the University of Oregon in some 160 human patients.

At each implanting procedure, the animal was induced to anesthesia with Surital,** and atropine sulfate*** was given to stabilize heart signs. The animal was intubated and maintained for the length of the operations on a oxygen-Halothane**** mixture. For each implant, an incision was made, mucosa and periosteum was reflected, and the implant was driven to place in alveolar bone above the apices of the teeth. To place the implant, a mallet and Matthou needle holder were used. The incision was closed using a single silk suture in most instances. Each site was tatooed with

* Donated by Wah Chang Corporation of Albany, Oregon.

** Parke-Davis & Co. 2.5% soln.

*** Eli Lilly & Co. 0.4 mg/cc

**** Ayers Laboratories Incorporated.

India ink to make identification easier after sacrifice of the animal. The animal was covered after each procedure with I.M. administration of Penicillin G,* 150,000 units. This was done to prevent multiplication of bacteria which may have been introduced from the animal's oral cavity at each surgical site. A bacterial infection and resulting inflammatory reaction would have given an unrepresentative bone healing picture adjacent to the implant.

The implants were placed into the maxilla of the animal such that at the time of sacrifice there were implants of age two days, and from one to nine weeks. These implants in the maxilla were placed without benefit of prior drilling of any guide holes. They were malleted to place at right angle to the bone surface using moderate force in a similar manner to that used in human subjects.

In the mandible, metal implants of eight different types were placed and left six weeks before sacrifice of the animal. These implants were placed into holes drilled into the mandibular alveolar bone using a 5-0 round bur. This was done because of the very dense nature of the mandible and because of the softness of some of these metals. In the mandible, implants of tantalum, elgiloy, 18-8 stainless steel, silver, gold, iron, and bronze were used. All implants were designed differently from those used clinically on human subjects in that they were provided with a right angle bend or "handle" which was left laying flat on bone after the rest of the implant was driven to place. This was done to make for easier removal of implants from the specimens before sectioning. Implants were all made of .022 inch diameter wire, 4.5 mm. in length.

All instruments and implants were washed and autoclaved before each

* Fort Dodge Laboratories.

procedure, but because of the difficulty of maintaining sterility in the canine's oral environment, no claim of sterile surgical technique is made.

After the nine-week sequence of implant placement, the animal was anesthetized for the final procedure. An incision was made vertically at the midline of the anterior cervical region and the right common carotid artery and left internal jugular vein were exposed and isolated. A canula was inserted in the common carotid artery and perfusion with normal saline was carried out until the internal jugular vein contained only the clear fluid from the head of the animal. Immediately, perfusion was begun with 10 percent formalin and continued until the animal's heart signs ceased. This required 900 cc. of formalin.

After sacrifice of the animal, the maxilla and mandible were removed and preserved in 10 percent formalin for two weeks. After this period of time, block sections of approximately two cm. cubes were made from the alveolar bone surrounding each implant (Fig. 1). These were decalcified in a sodium formate-formic acid solution for approximately ten days. The metal implants were then removed from the specimens (Fig. 2). The bone specimen were then imbedded in paraffin and sections were prepared on the microtome. Stains used included hematoxylin and eosin, and Masson's Trichromic stain for collagen.

FINDINGS

Tantalum Implants in the Maxilla:

The specimen of maxillary bone which was adjacent to a tantalum implant for two days before sacrifice of the animal demonstrated histologic evidence of mechanical trauma. Bone spicules were deflected in the direction of implant placement and the junction of implant and bone were very serrated. Many polymorphonuclear leukocytes (Fig. 3) and macrophages, and loose red blood cells were present in large numbers. However, no osteoclasts or osteoblasts were apparent two days after implant placement.

In contrast, the one-week bone specimen showed as its major feature, a great deal of osteoclastic activity. In addition, osteoblastic cells were apparent in moderate numbers in this section of tissue. At this stage, also, the presence of collagenous fibers and macrophages (Fig. 4) lining parts of the implant-bone junction were apparent.

After two weeks in maxillary alveolar bone, the sections continued to show large quantities of red blood cells near the junction of implant and bone. Also, many macrophages were visible throughout the implant site.

The three-week specimens continued to show many macrophages, in addition to osteoclastic and osteoblastic activity. Also, at this stage and throughout the remainder of the period of implant placement, the presence of a single layer of degenerating fibroblastic-appearing cells was seen in parts of the histologic section, lining the implant space (Fig. 5).

At four weeks, the major observation to be made was the diminished numbers of red blood cells as compared to previous sections. Collagenous

fibers were present in areas of the specimen separating the implant from bone (Fig. 6). Osteoblasts were seen in large numbers, as were limited numbers of macrophages.

At five weeks, many macrophages were still present. The collagenous layer between implant and bone was present circumferentially in some areas (Fig. 8). In other areas, paradoxically, the collagen layer was thick on one side of the longitudinal section of the implant and non-existent on the opposite side (Fig. 9). Many osteoblasts were visible in this section, their nuclei polarized away from the junction of cell and bone (Fig. 7).

Six weeks after tantalum implant placement, the single layer of degenerating fibroblastic cells were still present at the implant-bone junction. The presence of hemosiderin was apparent in some areas. Very few red blood cells were present. Osteoblasts were still active.

Both the seven and eight-week specimens showed macrophages, a degenerating single layer of spindle-shaped cells, and osteoblastic activity. Red blood cells were very scarce in the immediate implant area.

Measurement of the cross section of the implant area gives a diameter of approximately 1120 microns with fibrous areas varying in thickness from 14 to 420 microns (Fig. 4). The cross sectioned area corresponds in size to the .022 inch implants used in this study.

Implants of Various Metals in the Mandible After Six Weeks:

The appearance of the tantalum implant in the pre-drilled mandibular implant site was very similar to the maxillary six-week specimen which was tapped forceably to place without drilling a guide hole. Osteoblastic activity was present and macrophages were seen in the area. A layer of degenerating cells next to the implant was also present.

The 18-8 stainless steel implant site also showed osteoclastic activity and a degenerating spindle-cell layer.

The Elgiloy* implant displayed a thick collagenous layer in some areas at the implant-bone junction, and a single degenerative layer of cells in other areas. The implant of gold orthodontic wire also exhibited macrophages, thick layers of collagenous fibers in areas, and a single layer of spindle-cells in other areas. A few red blood cells were seen adjacent to the implant vacuole.

The implant of silver endodontic cone showed many macrophages in the section. Here again was observed a single layer of spindle-shaped cells in some areas next to the bone.

The implant of carbon-steel was unusual in that no cells were observed in the area adjacent to the implant space. This may represent artifact from preparation, however.

The bronze implant area exhibited osteoblastic activity and brown, hemosiderin-like particles. Nearly all maxillary and mandibular implant sites exhibited black granular particles which originally were thought to be macrophages containing hemosiderin degradation products. However, a Perls' Prussian Blue test for hemosiderin was performed and gave negative results. It was felt that these cells were dendritic melanophores rather than macrophages.

* Rocky Mountain Dental Product Company.

DISCUSSION

From our review of the literature, it was apparent that tantalum evolved as a material of choice in human implanting procedures through a trial and error process which took centuries. Tantalum (atomic number 73, atomic weight 180.9) came to be used in implanting because of its amazing physical properties which makes it ideal for this purpose. It is very resistant to chemical corrosion. It is inert to salts, whether dry, wet, or dissolved, except those which hydrolyze to strong alkalis. It is attacked at room temperature only by hydrofluoric acid. It is ductile and malleable in the cold state and its tensile strength equals that of cold-rolled steel. Tantalum was discovered in 1802, by the Swede, Ekeberg, who named it after the wayward son of Zeus. It is very difficult to isolate and was not produced commercially until 1922, when mining began in the Pilbarra district of Australia.

Despite the apparent inert qualities of tantalum, the findings of this paper indicate that tantalum, along with the other metals placed in bone, does elicit a response from osseous tissue. From the very first tissue section at two days, up until the last section at eight weeks, macrophages were observed in the tissues engulfing foreign particles. It may be that the products being engulfed were merely products of blood cell degredation. However, one wonders why blood cells would remain in these areas such a long time after the original insult to the tissues.

The continuing presence throughout the eight-week study of a degenerating layer of spindle cells at the bone-implant junction indicates

some type of trauma occurring to bone in this area. Quinton-Cox* has advanced the theory that the continuing degeneration of the adjacent bone layer results from pressure built up in tissues as a result of the tissues attempt to mechanically force the foreign body of the implant out of the tissue. He further suggests that differences in bone cell activity in different areas of the implant may be explained by differences in compactness of the bone in which the implant is placed. Very compact bone may cause more pressure on a driven implant than does bone with many marrow spaces present. Therefore, more bone cell activity should be observed in areas where compact bone is adjacent to the implant. In fact, it can be observed in several tissue sections that this is exactly what has happened.

In the sections where the thicker collagenous layers were present, the thickness of the fiber layer rarely exceeded 400 microns. Considering the length of implants used in human patients at the University of Oregon (1.2 mm.), it is difficult to imagine a tumbling of implants occurring within the bone in which they were placed. Even if the collagenous layer surrounding an implant was uniformly of 400 micron thickness, and if it were of loose enough consistency to allow movement, the length of the implant would prevent a significant tumbling motion.

The extreme variability in thickness of the capsule of fibers surrounding any single implant is in disagreement with the work of Laing.[46] He proposed a system of grading the suitability of materials for placement in living tissues based on the thickness of the connective capsule which formed around the implant. This is based on the theory that a thicker

* Personal communication.

capsule of connective tissue fibers indicated less suitability for implantation.

The fact that osteoblastic activity may still be observed after eight weeks seems to argue against a purely inert action of tantalum on bone. The work of Venable and Stuck[14] based on electrochemical reactions of metal in living tissue may help to explain the continued activity of bone forming cells and macrophages next to the implant after many weeks. These researchers proposed that in any instance where metals of two different types were placed in the same animal, an electrical potential was produced which would cause bone cell activity. Perhaps the many different metals placed in the single animal used in the present study did induce electrical activity and explains continued degeneration of cells adjacent to the implant.

It may also be noted that the histologic picture of tantalum and the other metals at six weeks was very similar. Perhaps the presence of tungsten in the tantalum wire used in this study negated its use as an inert implantation metal.

Previous researchers[51] have recorded the presence of necrotic tissue adjacent to implants which had guide holes drilled before placement of implants in bone. The present study found active cellular proliferation in the mandibular implants in all but one instance where holes were pre-drilled. The only exception was most likely an artifact resulting from tissue preparation and not actually from death of cells due to trauma from drilling.

It is worth noting that the human subjects in which implants were placed and in which implant tumbling was observed to have occurred, were growing youngsters. This is in contrast to the animal used in the study,

which was an adult. It may well be that a better comparison of results could have been made had a growing pup been used in this study. Perhaps then a better assessment of the effect of "periosteal sliding"[52] over implants due to apposition of bone at suture areas could have been made. It is felt that this is an unlikely possibility as to the cause of implant tumbling, however, because of the small amount of growth remaining to be completed in the jaws of orthodontic-patient age groups.[53]

It is felt that while the cause of implant tumbling has not been rigidly defined in this study, it can be said that the cause is probably not a result of connective tissue encapsulation. A more likely cause of tumbling is placement of implants imperfectly into areas of subcutaneous tissue, or into large bone marrow spaces rather than into solid compact bone.

A possibility for a more detailed study might involve the use of more animals and combine a histologic with a radiographic study. For a project of this nature, some type of cephalostat would have to be devised which would be extremely more accurate than the ear-post type of head holder. Or, it may be that the system proposed by Dennis[54] utilizing three-dimensional radiographs with four implants in a single bone would aid in determining radiographically which implants in an animal have tumbled. Those implants that have changed position could be compared histologically with those that have not moved to determine possible causes and solutions to the problem of implant tumbling.

SUMMARY

It was planned to study how bone healing progresses adjacent to implants which were driven into alveolar bone. To accomplish this, implants of the metal tantalum were driven on a weekly basis, for a period of eight weeks, into the maxilla of an adult cocker spaniel. Implants of various metals were placed into holes drilled into the mandible of the same animal and allowed to heal for six weeks. The animal was sacrificed and the tissues fixed and decalcified. The implants were removed and longitudinal and transverse sections were made of the implant sites. Staining of the specimens with hematoxylin and eosin and with Masson's Trichromic method was performed. The sections were examined microscopically and observations recorded.

CONCLUSIONS

1. Within two days, macrophages and polymorphonuclear leukocytes were present in bone areas adjacent to tantalum implants driven to place in alveolar bone.

2. Within one week, bone tissue adjacent to driven implants of tantalum was the site of osteoblastic and osteoclastic acitivity.

3. Continued irritation of bone by the implant was present after eight weeks as evidenced by:

   a) Active engulfment of particulate matter by macrophages.

   b) Degradation of cells adjacent to the implant.

   c) Osteoblastic activity in bone areas adjacent to implants.

4. The formation of a collagenous fiber capsule around tantalum implants is a highly variable phenomena and the width of the connective tissue capsule cannot be used as a criteria for the suitability of a material for implanting in living tissue.

5. Reaction of bone to the tantalum wire used in this study was similar to that elicited by a number of other metals.

6. Tumbling of implants, after their placement in bone, as a result of their encapsulation by connective tissue fibers is highly unlikely.

BIBLIOGRAPHY

1. Thorburn, B.: The Instrumentation for Placing Intraosseous Mettalic Implants and Their Reliability. Unpublished thesis, University of Oregon Dental School, 1965.

2. Bjork, A.: Facial Growth in Man, Studied with the Aid of Metallic Implants. Acta Odont. Scand. 13:9, 1955.

3. Bjork, A.: Variations in the Growth Pattern of the Human Mandible: Longitudinal Radiographic Study by the Implant Method. J. Dent. Res., Suppl. to No. 1, 42:400, 1963.

4. Bjork, A.: Sutural Growth of the Upper Face Studied by the Implant Method. Acta. Odont. Scand. 24:109, 1966.

5. Herschfus, L.: Histopathologic Findings on Vitallium Implants in Dogs. J. Pros. Dent. 4:413, 1954.

6. Zierold, A.A.: Reaction of Bone to Various Metals. Arch. Surg. 9:365, 1924.

7. Hales, S.: Statistical Essays: Vol. 1, Vegetable Statistics, London, W. Innys and others, 1727, p. 337.

8. Payton, C.: The Growth in Length of the Long Bones in the Madder-Fed Pig. J. Anat. 66:414, 1932.

9. Hunter, J. cited from Dobson, J.: Pioneers of Osteogeny: 1728-1793. J. Bone Joint Surg. 30B:361, 1948.

10. Levert, H.S.: Experiments on the Use of Metallic Ligatures as Applied to Arteries. Am. J. Med. Science. 4:17, 1829.

11. Langenbeck, G. cited from Burke, G.L.: The Corrosion of Metals in Tissues; and an Introduction to Tantalum. Canad. Med. Assn. J. 43:125, 1940.

12. Flourens, M. cited from Payton, C.: The Growth in Length of the Long Bones in the Madder-Fed Pig. J. Anat. 66:414, 1932.

13. Ollier, M. cited from Payton, C.: The Growth in Length of the Long Bones in the Madder-Fed Pig. J. Anat. 66:414, 1932.

14. Humphery, G. cited from Brodie, A.G.: On the Growth Pattern of the Human Head from the Third Month to the Eighth Year of Life. Am. J. Anat. 68:209, 1941.

15. Lister, J.: The Treatment of Fracture of the Patella. Brit. M.J. 2:855, 1883.

16. Nichols, F.C.: Semi-buried Denture Implants. Review of Literature and Experimental Study. J. Oral. Surg. 12:217, 1954.

17. Kitteredge, T.A.: A Case of Fracture of the Patella, With a New Method of Wiring. Boston Med. & Surg. J. 125:544, 1891.

18. Lane, W.A.: The Operative Treatment of Simple Fractures (With Special Plate). Brit. M. J. 2:1325, 1905.

19. Brickner, W.M.: Metal Bone Plating a Factor in Non-Union. Am. J. Surg. 28:16, 1914.

20. Albee, F.H.: The Inlay Bone Graft as a Treatment of Ununited Fractures. Am. J. Surg. 28:21, 1914.

21. Magruder, E.P.: The Treatment of Fractures. Am. J. Surg. 28:1, 1914.

22. Groves, E.W.H.: Cited by Zierold, A.A.: Reaction of Bone to Various Metals. Arch. Surg. 9:365, 1924.

23. Mann, A.T.: Nails and Screws in Fractures. J.A.M.A. 67:1148, 1916.

24. Trout, B.: Autogenous Bone Grafts Versus Lane's Plates. Ann. Surg. 61:717, 1915.

25. Von Baeyer, cited by Clark, E.G.: An Investigation into the Correlation Between the Electrical Potentials of Metals and Their Behavior in Biological Fluids. J. Bone & Joint Surg. 35:467, 1953.

26. Dubreuil, G. cited by Sissons, H.:Experimental Determination of Rate of Longitudinal Bone Growth. J. Anat. 87:228, 1953.

27. Haas, S.L.: Interstitial Growth in Growing Long Bones. Arch. Surg. 12:887, 1926.

28. Gatewood, L. and Mullen, B.P.: Experimental Observations on the Growth of the Long Bones. Arch. Surg. 15:215, 1927.

29. Menegaux, cited by Clark, E.G.: An Investigation into the Correlation Between the Electrical Potentials of Metals and Their Behavior in Biological Fluids. J. Bone & Joint Surg. 35:467, 1953.

30. Bisgard and Bisgard: Longitudinal Growth of Long Bones. Arch. Surg. 31:568, 1935.

31. Northfield, D.W.C.: On the Fate of Metallic Foreign Bodies Introduced into Tissues in the Treatment of Fractures. Guy Hosp. Report. 86:159, 1936.

32. Jones, L. and Lieberman, B.A.: Interaction of Bone and Various Metals; Vanadium Steel and Rustless Steels. Arch. Surg. 32:990, 1936.

33. Venable, C.S. and Stuck, W.G.: Effects on Bone of Presence of Metals: Based upon Electrolysis; Experimental Study. Ann. Surg. 105:917, 1937.

34. Gudden, B. cited from Giblin, N. and Alley, A.: A Method of Measuring Bone Growth in the Skull. Anat. Rec. 83:381, 1942.

35. Bunnell, S.: Primary Repair of Severed Tendons. Am. J. Surg. 47:502, 1940.

36. Burke, G.L.: The Corrosion of Metals in Tissues; And an Introduction to Tantalum. Canad. Med. Assn. J. 43:125, 1940.

37. Carney, H.M. and Bunch, J.C.: An Experimental Study with Tantalum. Proceedings of the Society for Experimental Biology and Medicine. 51:147, 1942.

38. Bernier, J.L. and Canby, C.P.: Histologic Studies of the Reaction of Alveolar Bone to Vitallium Implants. J.A.D.A. 30:188, 1943.

39. Venable, C.S. and Stuck, W.G.: General Considerations of Metals for Buried Appliances in Surgery. Int. Abstr. Surg. 76:297, 1943.

40. Clark, E.G. and Hickmann, J.: An Investigation into the Correlation Between the Electrical Potentials of Metals and their Behavior in Biological Fluids. J. Bone and Joint Surg. 35:467, 1953.

41. Nichols, F.C.: Semi-Buried Denture Implants. Review of Literature and Experimental Study. J. Oral Surg. 12:217, 1954.

42. Krebs, A.: Expansion of the Mid-Palatal Suture Studied by Means of Metallic Implants. Acta Odont. Scand. 17:491, 1959.

43. Cohen, J.: Tissue Reaction to Metals--The Influence of Surface Finish. J. Bone Joint Surg. 43A:687, 1961.

44. Isaacson, R.J. and Murphy, T.D.: Some Effects of Rapid Maxillary Expansion in Cleft Lip and Palate Patients. Angle O. 34:143, 1964.

45. Coccaro, P.J. and Lloyd, R.S.: Behavior of Points A & B in Denture Patients. A. J. O. 51:183, 1965.

46. Laing, P.G.: Tissue Reaction in Rabbit Muscle Exposed to Metallic Implants. J. Biomed. Res. 1:135, 1967.

47. Held, A.J. and Spirgi, M.: Osteoperiosteal Response to Various Implants in Rabbits. Helv. Odont. Acta. 12:1, 1968.

48. Kaminski, E., et al.: The Behavior of Biological Materials at Different Sites of Implantation. J. Biomed. Mat. Res. 2:81, 1968.

49. Sarnat, B.: Growth of Bones as Revealed by Implant Markers in Animals. Am. J. Phys. Anthrop. 29:255, 1968.

50. Turpin, D.L.: Growth and Remodeling of the Mandible in the Macaca Monkey. Am. J. Ortho. 54:251, 1968.

51. Collins, D.H.: Structural Changes Around Nails and Screws in Human Bones. J. Path. Bact. 65:109, 1953.

52. Keith, A.: Bone Growth and Bone Repair. Brit. J. Surg. 5:685, 1918.

53. Hixon, E.H.: The Nature of Orthodontic Diagnosis. C.V. Mosby Co. St. Louis, 1966.

54. Dennis, H.S.: The Reliability of a Three-Dimensional Cephalometric Technique. Unpublished thesis, University of Oregon Dental School, 1972.

Fig. 1 Specimen of Alveolar Bone from the Experimental Dog Showing the Metal Implant in Place with the Right Angle "Handle" Resting on the Surface of the Bone.

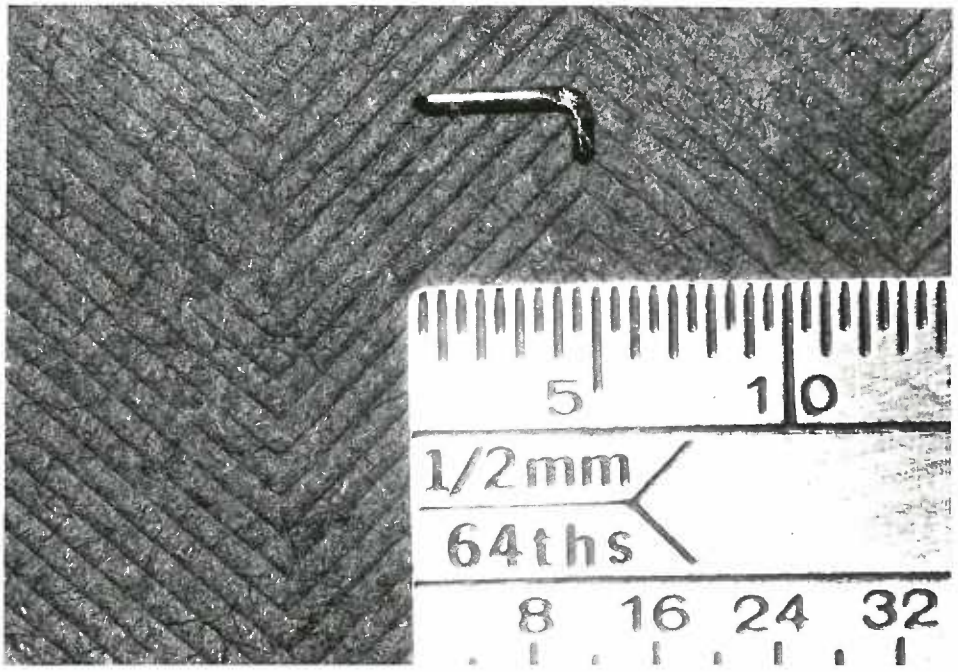

Fig. 2 The Design of the Metal Implants is Shown Here, Illustrating the Right Angle Bend used for Ease of Finding and Removing the Implant After Sacrifice of the Animal.

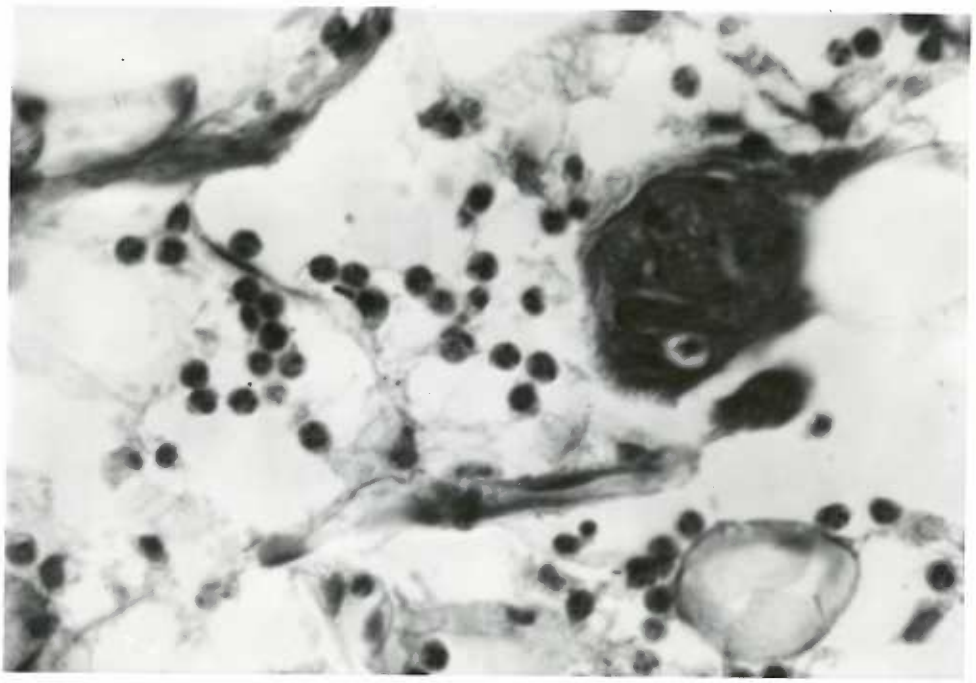

Fig. 3 Aggregations of Polymorphonuclear Leukocytes Adjacent to the Implant Site in the Two-day Specimen.

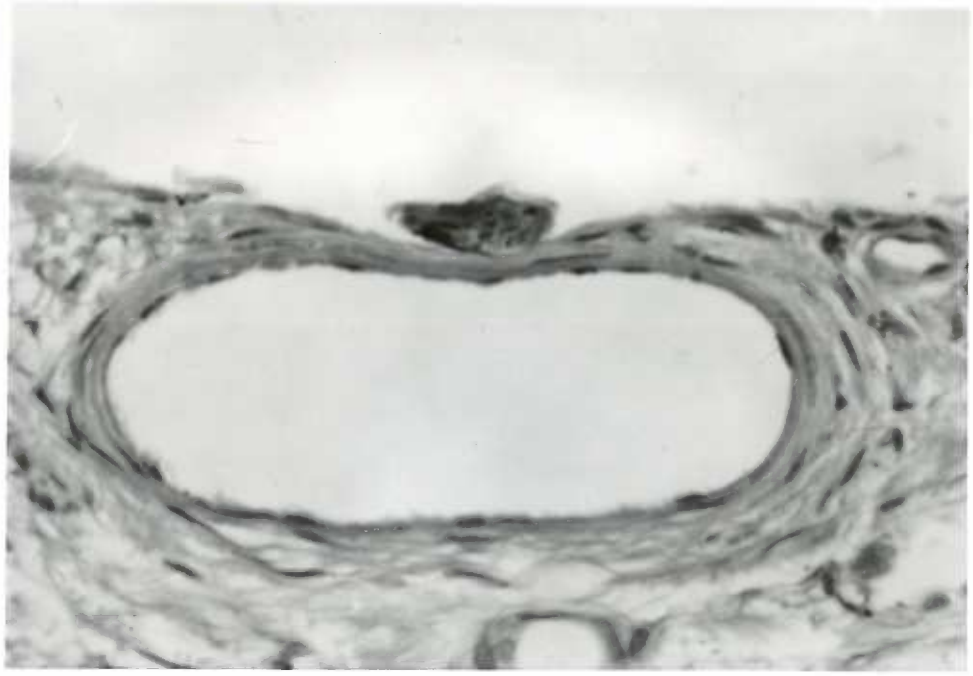

Fig. 4 A Large Macrophage is Seen Here Adjacent to a Blood Vessel and Lining the Implant Site of the One-week Specimen.

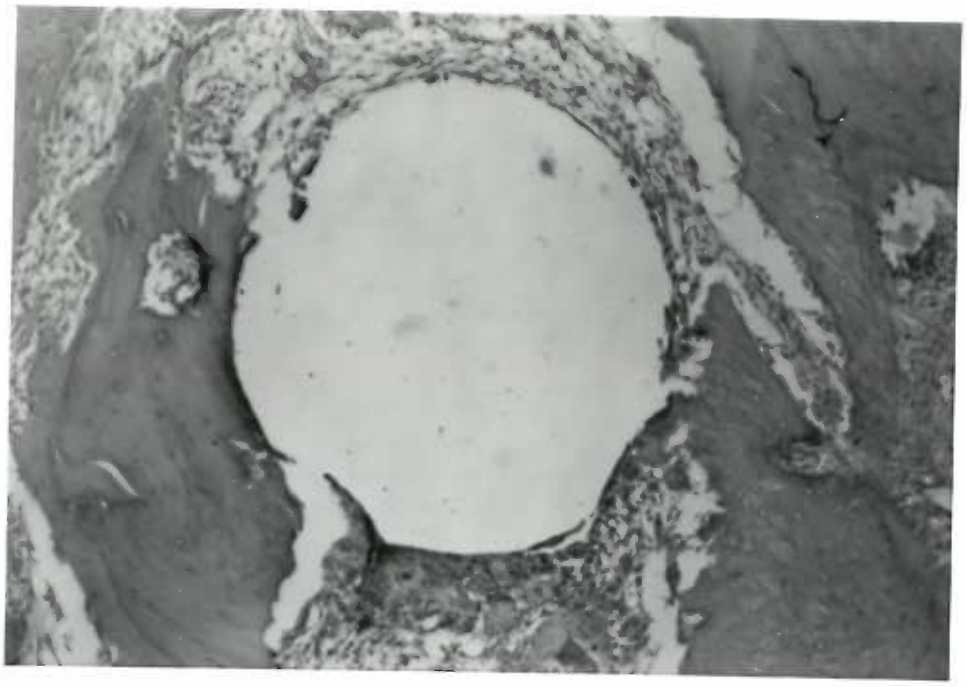

Fig. 5 This View Shows a Cross Section of the Implant Site With Areas of Thick and Thin Fibrous Tissue Between the Implant Site and Bone. Much Osteoclastic Activity is Present.

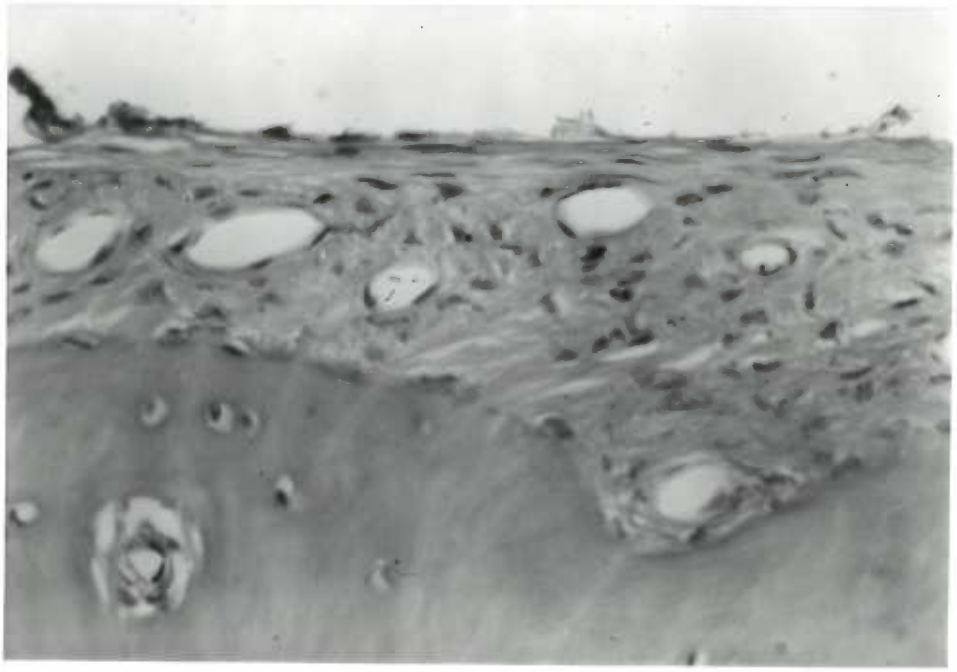

Fig. 6 This View Shows a 140 Micron Area of Collagenous Fibers Between the Implant Site and Bone Surface.

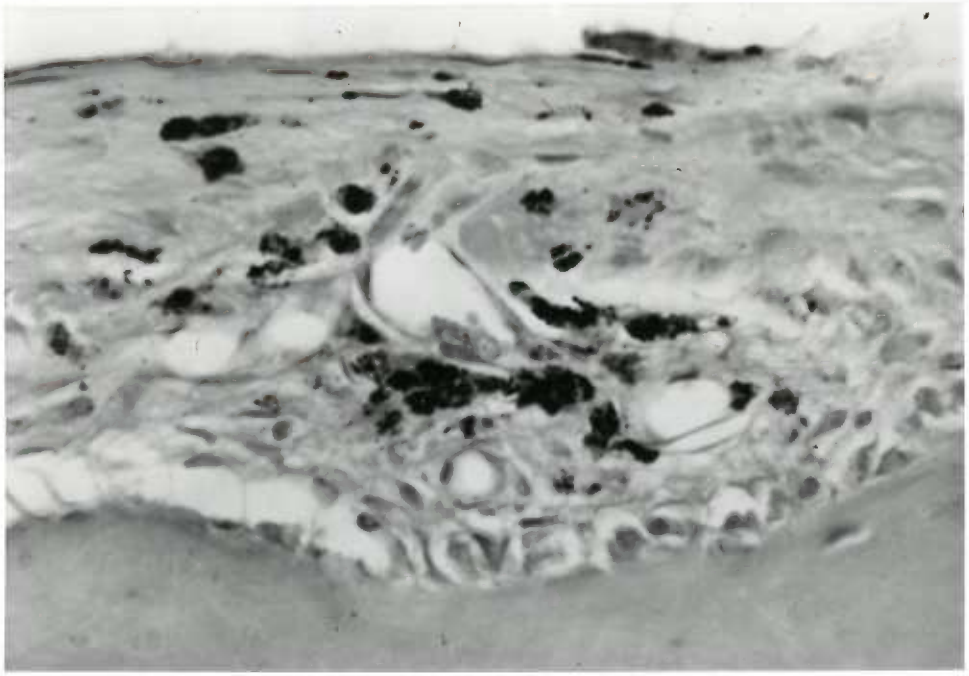

Fig. 7 Osteoblastic Activity at the Junction of Bone and Fibers near a Group of Dendritic Melanophores.

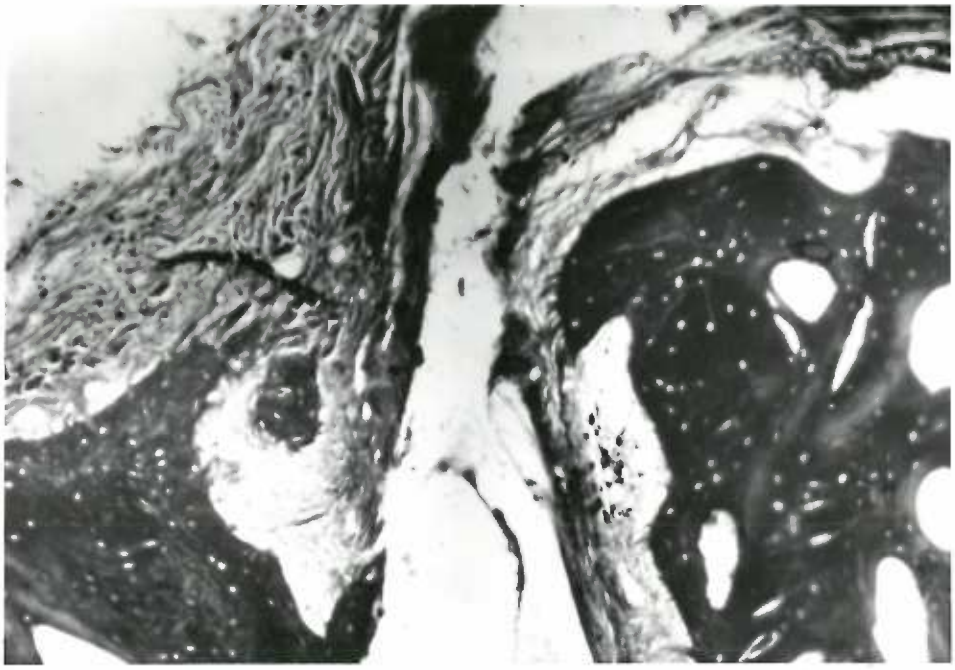

Fig. 8 This View Illustrates One of the Rare Areas in Which Connective Tissue Fibers Completely Surround the Implant Site. This Area is Near the Point of the Five-week Implant Site.

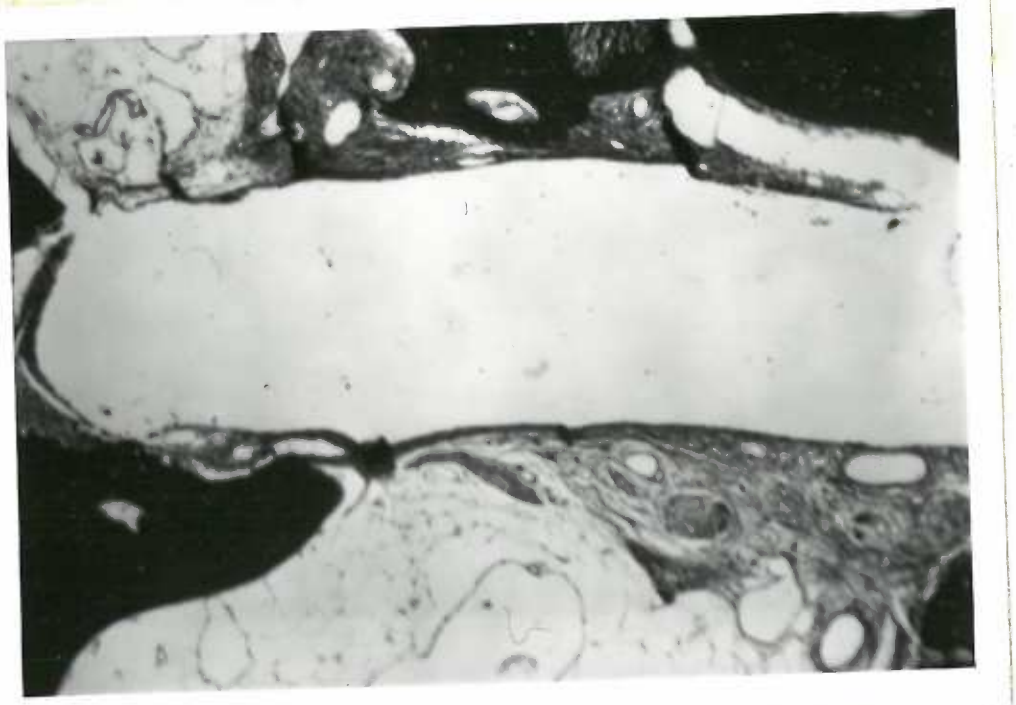

Fig. 9 This View Illustrates a Longitudinal Section of the Five-week Implant Site with Areas of Thick Fibrous Tissue Separating Implant and Bone and also Areas of Only One Cell Layer Separating Implant Site and Bone.