Osseointegrated titanium implants for maxillofacial protraction in monkeys

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Titanium implants were placed surgically into the maxillary, zygomatic, frontal, and occipital bones of four pigtail monkeys. After a 4-month healing period, the implants were exposed and abutments were placed. Extraoral traction appliances were then attached to the abutments. The cranial implants were used to support the framework of the traction appliance; those in the facial bones were used to attach springs that delivered a protraction force. The application of force varied among animals. In animal A, the force was applied to the maxilla. In animal B, the force was applied to the zygomatic bones. Animals C and D had force applied to both the maxillary and zygomatic bones. A tensile force of 600 gm per side was maintained until approximately 8 mm of maxillary anterior displacement had occurred. This amount of movement required 12 weeks of force application in animals A and B, and 18 weeks in animals C and D. Cephalometric and dry skull analyses showed that the amount of skeletal protraction was significant. The findings also demonstrated that it was possible to control the direction of maxillary protraction. The facial implants remained immobile throughout the experiment. (AM J ORTHOD DENTOFAC ORTHOP 1988;94:285-95.)

Orthodontists routinely use teeth for the application of force to bone to effect skeletal change. Reliance on the teeth in this way is not only convenient but necessary since no other reliable means for applying forces to the craniofacial complex have been available. Unfortunately this indirect application of force limits the potential for orthopedic change and often causes undesirable tooth movement.[1-3]

The use of skeletal anchorage to apply force directly to bone would be more desirable. Two methods of skeletal anchorage have been reported: intentionally ankylosed teeth[4,5] and endosseous implants.[6-10] Intentionally ankylosed teeth, however, have limited longevity since the roots ultimately resorb and the teeth exfoliate. Furthermore, their location may not facilitate optimal correction of the skeletal deformity. Endosseous implants, on the other hand, can be placed in various locations within bone. However, with the exception of osseointegrated titanium implants, endosseous implants have not been shown to remain stable on a long-term basis.[11-13]

Osseointegration has been defined by Brånemark and co-workers[14] as the direct contact between vital bone and the implant surface. This concept has been documented by light microscopy,[14-17] radiography,[16] scanning electron microscopy,[16,17] transmission electron microscopy,[16,17] Auger electron spectroscopy,[18] and energy-dispersive analysis of x-rays.[16] Osseointegrated titanium implants have had excellent long-term success in the treatment of edentulous jaws.[14,19] They also have been used extraorally for the attachment of facial prostheses[20] and hearing aids.[21] Therefore at this time osseointegrated titanium implants appear to be the implant of choice for achieving direct anchorage to bone.

Although skeletal anchorage has many potential uses in orthodontics, protraction of the maxillofacial complex was believed to be particularly suited for the

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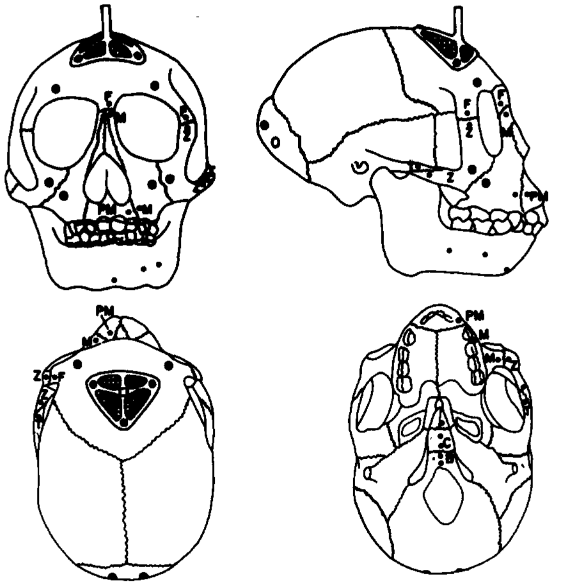

Fig. 1. Schematic illustration of a monkey skull (frontal, lateral, coronal, and basilar views) showing the location of tantalum markers *(small dots)*, cephalometric head positioner, and titanium implants *(large dots)*. *F*, Frontal bone; *M*, maxilla; *PM*, premaxilla; *Z*, zygomatic bone; *T*, temporal bone; *CB*, cranial base; *O*, occipital bone.

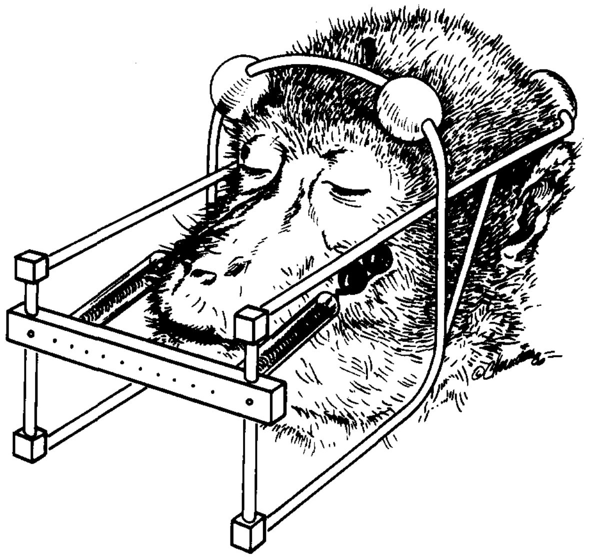

Fig. 2. Illustration of the extraoral traction appliance. The framework was rigidly attached with self-curing acrylic resin to the four cranial titanium implants. A precision coil spring with a protective tube was fastened bilaterally from the adjustable anterior horizontal bar of the framework to the facial titanium implants.

application of this technology. The purpose of this investigation then was to determine whether titanium implants in facial bones would remain stable when placed under traction and provide anchorage for protraction of the maxillofacial complex.

MATERIALS AND METHODS

The sample consisted of four 26- to 29-month-old male monkeys *(Macaca nemestrina)* in the mixed dentition (animals A, B, C, and D). They were provided and maintained by the Regional Primate Research Center at the University of Washington. The animals were caged individually without restraint and fed a normal diet of high protein monkey chow, fruit, and water ad libitum. Control data from an age- and sex-matched *Macaca nemestrina* monkey were obtained also from the Regional Primate Center.

Animal preparation

Several surgical procedures were necessary to prepare the animals for experimentation. The procedures were performed under sterile conditions with the animals induced into general anesthesia with ketamine hydrochloride (10 mg/kg) and maintained with halothane.

Tantalum markers. Eighteen markers, 1.5 mm in length and 0.5 mm in diameter, were implanted in the craniofacial complex of each monkey according to the technique described by Björk[22] and modified by Van Ness.[23] They were placed in the cranial base, mandible, and on each side of the left zygomaticomaxillary, zygomaticotemporal, zygomaticofrontal, frontomaxillary, and premaxillomaxillary sutures (Fig. 1). The tantalum markers allowed accurate superimposition of serial cephalometric radiographs and served as reference points for measuring spatial changes.

Cephalometric head positioner. A Vitallium* cephalometric head positioner was placed subperiosteally on the frontal bone of each monkey and secured in position with screws (Fig. 1). When coupled to a cephalostat, the head positioner ensured a static and reproducible head orientation for serial cephalometric radiographs. These preparatory surgical procedures have been described in detail by Van Ness[24] and Shapiro.[1]

Titanium implants. Eight endosseous titanium implants† (99.8% pure) were placed in the craniofacial complex of each animal (Fig. 1). Four implants were placed in the cranium (two in the occipital protuberance and one in each supraorbital ridge). The other four were placed bilaterally on each side of the zygomaticomaxillary suture (two in the maxilla and one in each zygomatic bone). The implants were cylinder-shaped, threaded, 5.0 mm in length, and 3.75 mm in diameter with a proximal flange 5.5 mm in width.

Surgical placement of the implants was performed with minimal trauma in a manner similar to that de-

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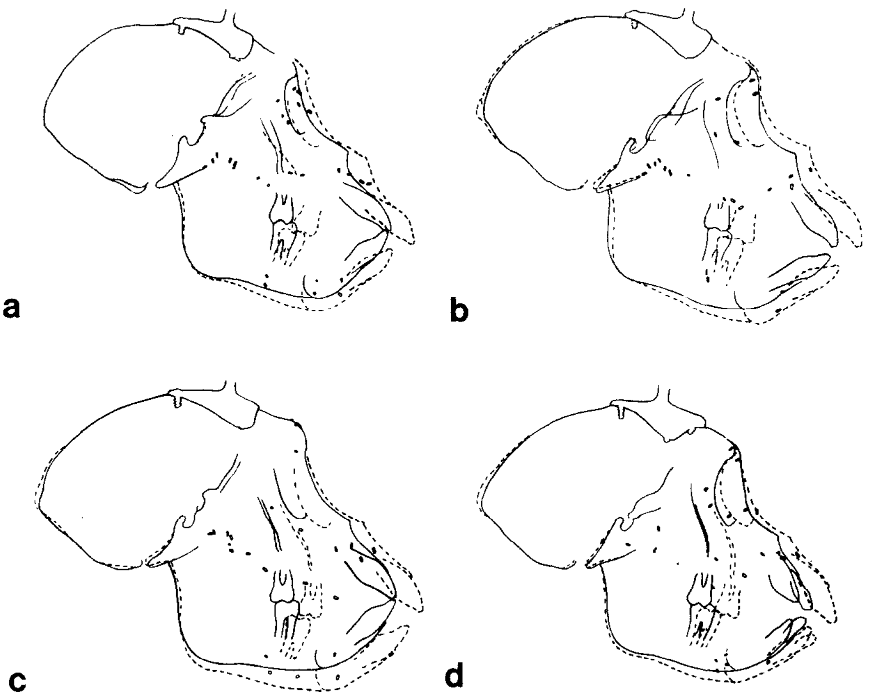


Fig. 3. Composite tracings of pre- and immediate postexperimental lateral cephalometric radiographs of animals A, B, C, and D. **a,** Animal A; **b,** animal B; **c,** animal C; **d,** animal D. The *solid line* represents preexperimental relationships; the *dashed line* represents postexperimental relationships. Overall lateral superimpositions were oriented on stable tantalum markers in the postsphenoidal portion of the cranial base, on the general contour of sella, and on the implanted head positioner.

Table I. Description of animals and experimental protocol

Animal	*Age at time of implant placement (mo)*	*Healing period (wk)*	*Location of force application*	*Force magnitude (gm)*	*Duration of force application (wk)*	*Retention period (wk)*	*Postretention period (wk)*
A	26	14	Maxilla	600	12**	—	—
B	29	13	Zygomatic bones	600	12**	—	—
C	27	13	Maxilla and zygomatic bones	600	18	None	None
D	27	15	Maxilla and zygomatic bones	600	18	12	8
Control	30*						

*Age at death.
**Killed following force application.

scribed by Tjellström and associates.[21] Armamentarium for the procedure was supplied by Bofors AB, Sweden. The bone was exposed by incising and reflecting the overlying soft tissues. Holes were drilled and enlarged with a series of twist drills. The holes were threaded with a tap and the implants were screwed gently into place. The entire procedure was carried out under profuse irrigation with room-temperature saline. Protective cover screws were placed on the implants to prevent bone overgrowth during healing. Primary closure of each surgical site was achieved by repositioning and suturing the reflected flap.

The implants were reexposed surgically after a 13- to 15-week healing period. The cover screws were re-

Table II. Changes in distance between sutural tantalum markers measured from tracings of lateral cephalometric radiographs

	Displacement of tantalum markers (mm)														
	PPM			*ZT*			*ZF*			*ZM*			*FM*		
Animal	*P*	*D*	*Difference*	*P*	*D*	*Difference*	*P*	*D*	*Difference*	*P*	*D*	*Difference*	*P*	*D*	*Difference*
A	9.0	7.5	−1.5	1.5	4.0	2.5	0	3.0	3.0	4.0	—*	—	3.0	5.0	2.0
B	7.5	7.0	−0.5	2.5	18.0	15.5	0	8.0	4.0†	3.0	—*	—	0.5	0.5	0‡
C	9.0	8.5	−0.5	2.0	8.0	6.0	—*	3.0	—	—*	12.0	—	0	0	0‡
D	7.5	7.0	−0.5	0	15.0	15.0	0.5	7.5	7.0	11.0	—*	—	0	4.0	2.0†

PPM, Premaxillomaxillary; *ZT*, zygomaticotemporal; *ZF*, zygomaticofrontal; *ZM*, zygomaticomaxillary; *FM*, frontomaxillary.
P, Refers to tantalum marker implanted proximal to suture.
D, Refers to tantalum marker implanted distal to suture.
*Markers were obscured from view by the titanium implants or the extraoral appliance.
†Measured difference may be less than calculated difference between the proximal and distal markers due to directional change.
‡Markers were not implanted across suture.

moved and the implants were cleaned of all hard- and soft-tissue remnants. Cylinder-shaped titanium abutments,* 4.5 mm wide and 8.0 mm long, were attached to the osseointegrated implants with abutment screws. The skin surrounding each abutment was repositioned and sutured.

Extraoral traction appliance

After placing the abutments on the implants, an alginate impression of each monkey's head was made and poured in dental stone. Metal frameworks were fabricated from the stone casts by the Scientific Instrument Division of the University of Washington. The frameworks, made from stainless steel needle stock tubing, were rigid and lightweight. They were attached with self-curing acrylic resin to the abutments of the four osseointegrated cranial implants (Fig. 2). An adjustable anterior bar permitted changes in the direction that traction was applied.

Force application

Protraction forces were delivered to the maxilla and/or zygomatic bones of each monkey by fastening precision coil springs (Saif-spring†) from the anterior bar of the extraoral traction appliance to the osseointegrated facial implants. Animal A had springs attached only to the implants in the maxilla and animal B had springs attached only to the implants in the zygomatic bones. Animals C and D had springs attached to the implants in both the maxillae and zygomatic bones (Table I). The force level was maintained at approximately 600 gm per side during the experimental period.

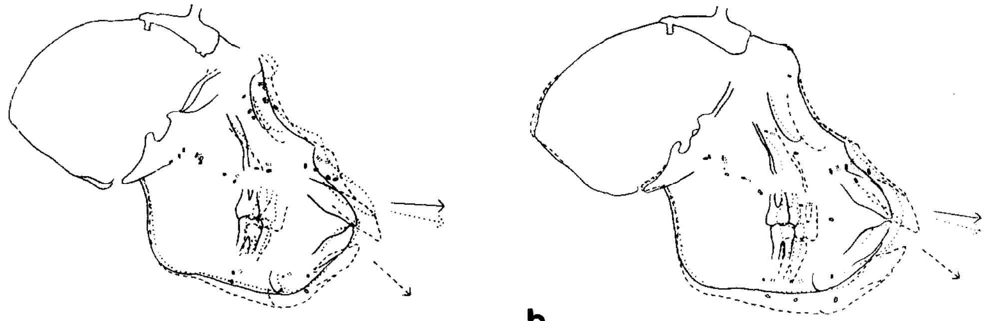
*Nobelpharma AB, Göteborg, Sweden.
†Unitek Corp., Monrovia, Calif.

The anterior bar of the extraoral appliance was adjusted initially to direct the force parallel to the occlusal plane. The magnitude and direction of force were monitored and adjusted at 2-week intervals.

The protraction force was maintained until approximately 8 mm of anterior displacement of the maxillofacial complex had occurred. This measurement was made at the premaxillomaxillary tantalum markers. At the end of force application, animals A and B were killed and perfused with normal saline solution followed by 10% buffered formalin. The springs and framework were removed in animal C. In animal D, the springs were replaced with wires to retain the experimental results for 12 weeks.

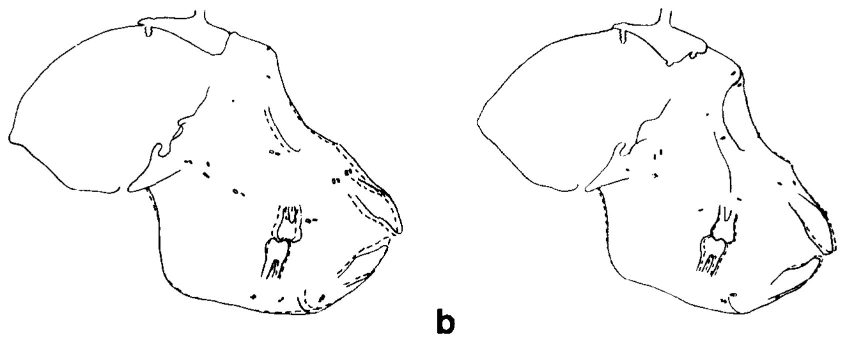
Documentation of changes

Clinical estimates of inflammation and mobility were recorded for each implant at 2-week intervals. Inflammation was assessed subjectively by evaluating tissue color, contour, and the tendency for hemorrhage or suppuration. Inflammation was rated as nonexistent, mild, moderate, or severe. Mobility was measured on a scale of 0 through 3 (0 = no mobility, 1 < 0.5 mm of mobility, 2 = 0.5 to 1.0 mm of mobility, and 3 > 1.0 mm mobility). Lateral and posteroanterior cephalometric radiographs were made at the start of force application and at 2-week intervals thereafter. The head of each animal was oriented reproducibly in a cephalostat using the implanted head positioner. The mandible was positioned in centric relation. The radiographs were exposed with a standard object-to-tube distance of 5 feet and an object-to-film distance of 14 cm. Exposures were made at 90 kV(p) and 200 mA with a time of 1.5 seconds for lateral views and 2 seconds for posteroanterior views.



a b

Fig. 4. Composite tracings of experimental lateral cephalometric radiographs of animals A and C showing the rotational changes that occurred when the direction of traction was varied. **a,** animal A; **b,** animal C. The *solid line* represents the relationships at the start of force application with the direction of force parallel to the occlusal plane. The *dotted line* represents the relationships after 6 weeks of traction in animal A and 8 weeks in animal C, at which time the direction of traction was moved inferiorly. The *dashed line* represents the relationships at the end of force application.



a b

Fig. 5. Composite tracings of postexperimental lateral cephalometric radiographs of animal C **(a)** and animal D **(b)** showing the changes that occurred with no retention **(a)** and those that occurred during the postretention interval **(b)**. The *solid line* in **a** represents the relationships at the end of force application and the *dashed line* 4 weeks later. The solid line in **b** represents the relationships at the end of retention and the dashed line the relationships 10 weeks postretention.

Tracings of cephalometric radiographs were superimposed to evaluate changes in the relationships of skeletal and dental structures. Overall lateral superimpositions were oriented on stable tantalum markers in the postsphenoidal portion of the cranial base, on the general contour of sella, and on the implanted head positioner. Changes were determined by registering the horizontal and vertical movements of the implanted tantalum markers relative to the animal's original occlusal plane.

Dry skulls and histologic specimens were prepared from the heads of animals A, B, and C. The heads were sectioned midsagittally and the left halves were placed in a commercially available enzyme solution (10% laundry presoak) for soft-tissue removal. The right halves were preserved in 10% formalin for histologic analysis. The zygomaticotemporal sutures from animals B, C, and the control were excised, embedded, sectioned, and stained with hematoxylin and eosin and Mallory's aniline blue collagen stain.

The titanium implants and surrounding bone from the right side of animals A, B, and C were analyzed histologically and radiographically. A trephine burr with profuse irrigation was used to remove the implants en bloc. The extracted implants were placed in 10% formalin and sent for processing to the Laboratory of Experimental Biology at the University of Göteborg, Sweden. The tissue blocks were sectioned at 10-μm intervals and examined under light microscopy.

RESULTS

The four monkeys remained healthy and experienced normal weight gain during the experimental period. The appliances were tolerated well with no apparent discomfort. Protraction of the maxillofacial complex began slowly, but progressed rapidly until the force

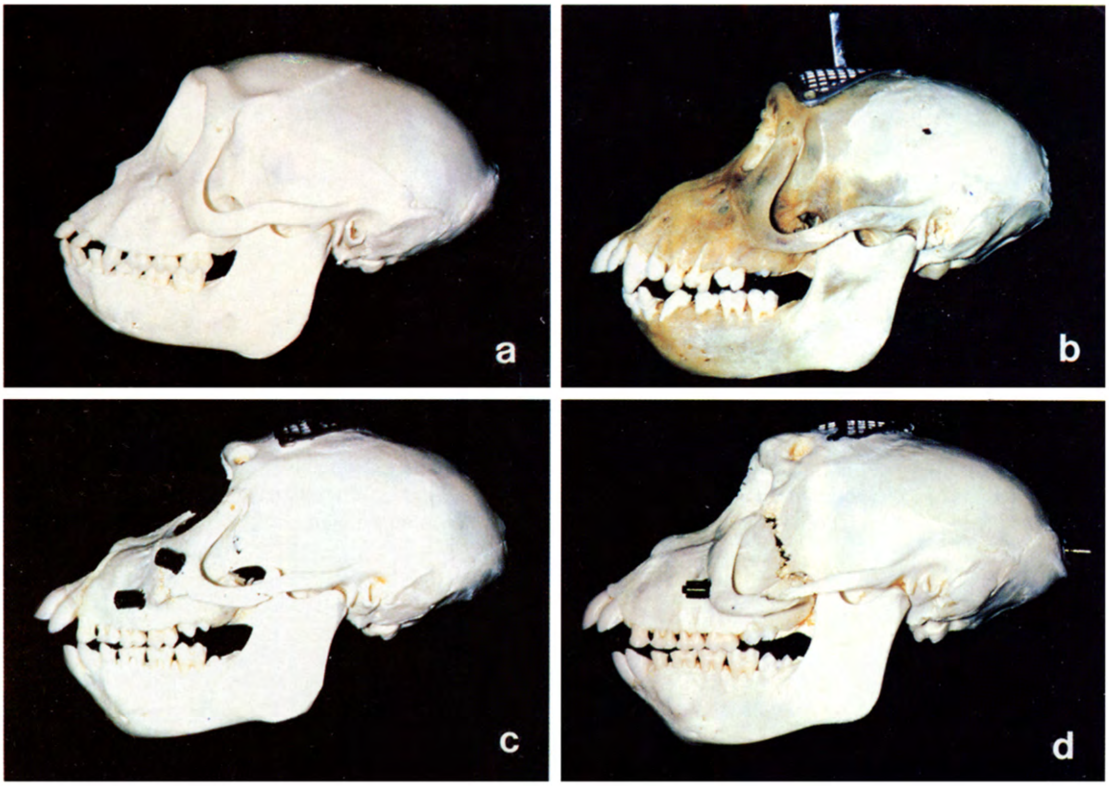


Fig. 6. Dry skull preparations showing the left side from the control animal **(a)**, an experimental animal from a previous study in which a protraction force was applied to splinted maxillary teeth **(b)**, experimental animal A **(c)**, and experimental animal B **(d)**. Animals A and B show considerable skeletal remodeling and sutural expansion compared with the control or the animal that had traction applied to the teeth. (Part **b** from Jackson GW, Kokich VG, Shapiro PA. AM J ORTHOD 1979;75:318-33.)

was stopped. The protraction force was applied for 12 weeks in animals A and B, and 18 weeks in animals C and D. The period of force application for animals C and D was longer because of their slower responses.

Cephalometric analysis

The superimposed tracings of pre- and immediate postexperimental lateral cephalometric radiographs showed that the maxillofacial complex was protracted significantly in all animals (Fig. 3). The displacement of the tantalum markers indicated that movement of the individual bones varied considerably among animals with respect to magnitude and direction of change (Table II). The greatest change occurred between the markers located across the zygomaticotemporal suture of animal B where the amount of separation measured nearly 16 mm (proximal and distal markers were displaced 2 mm and 18 mm, respectively). The head film superimpositions showed that the initial displacement of the tantalum markers, particularly those across the premaxillomaxillary suture, was in an anterosuperior direction (Fig. 4). As the direction of force was changed by moving the anterior bar of the traction appliance inferiorly, movement of the markers became directed more anteroinferiorly. Changes were noted also in the cranial base and occipital bone of three animals (Fig. 3, *a, b,* and *d*). The cranial base angle decreased approximately 5° because of flexure of the ventral leg; the posterior border of the occipital bone moved posteriorly approximately 2 mm.

Although no significant effects were observed in the intramaxillary dental relationships, skeletal changes resulted in altered intermaxillary dental relationships (Fig. 3). Angle relationships changed from Class I to Class II. Anterior open bites developed and overjet increased to between 5 and 7 mm. Slight distal tipping of the maxillary first molars was seen in two animals. Mandibular position changed in response to positional changes of the maxilla.

Superimposed tracings of the postexperimental head films of animals C and D showed that some relapse of the experimental result occurred in both animals. The amount of relapse, measured at the premaxillomaxillary tantalum markers, was approximately 2 mm and was directed primarily posteriorly. The relapse occurred during the first 2 weeks after removal of the protraction force. No significant changes were noted thereafter (Fig. 5).

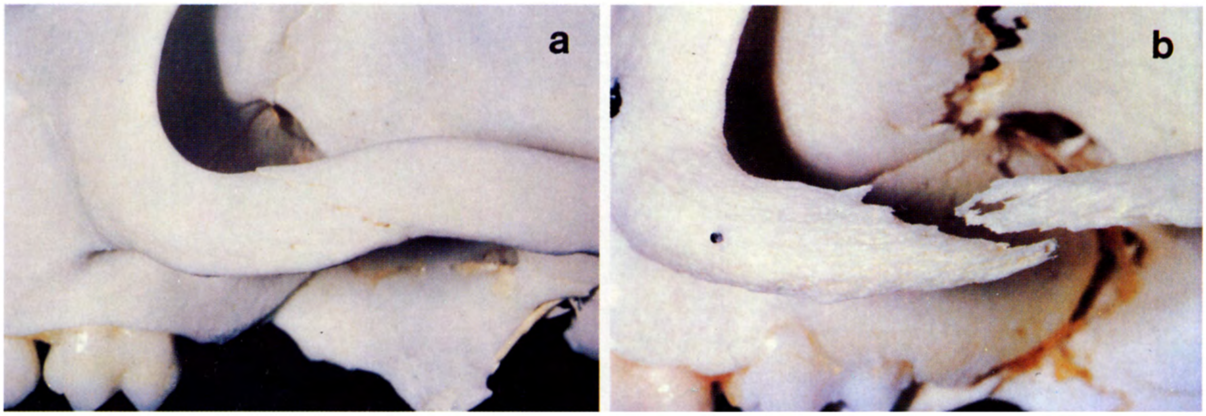


Fig. 7. Dry skull preparations showing the left zygomaticotemporal sutures from the control animal **(a)** and experimental animal B **(b).** At the termination of force application, the zygomatic and temporal processes were disarticulated in animal B. The histologic preparation of the right zygomaticotemporal sutures from these animals is found in **Fig. 12, a** and **b.**

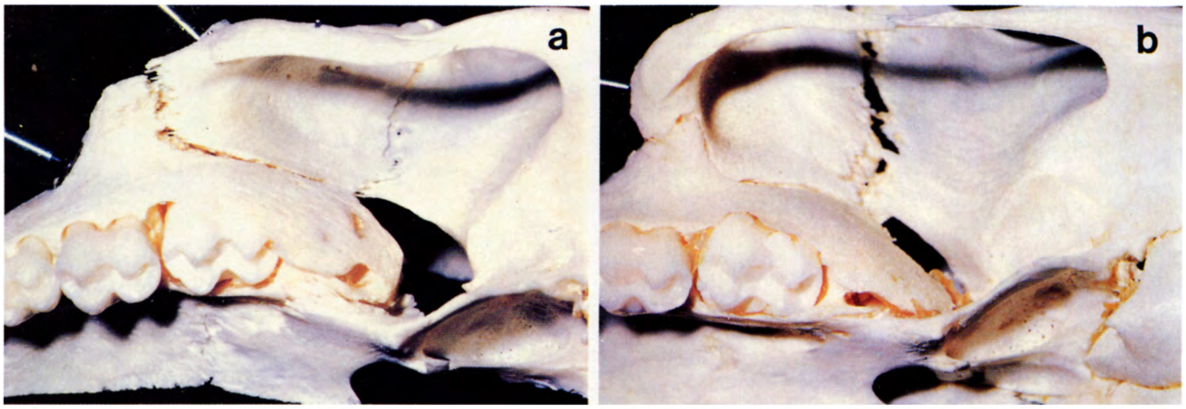


Fig. 8. Dry skull preparations showing the different effects when the protraction force was applied to titanium implants in the maxilla **(a)** and the zygomatic bones **(b).** Traction delivered to the maxillary implant **(a)** resulted primarily in significant separation of the zygomaticomaxillary suture. In contrast, traction applied to the zygomatic implant **(b)** changed the morphology of the zygomatic bone substantially and nearly disarticulated the sphenozygomatic and zygomaticotemporal sutures. The pterygomaxillary fissure was more enlarged in **a** than in **b.**

Dry skull analysis

The dry skulls of animals A and B corroborated the cephalometric findings. Most apparent was the enormous amount of sutural expansion created, which differed considerably among animals (Figs. 6 through 10). The bones adjacent to the zygomaticotemporal suture of animal B were disarticulated completely (Fig. 7, *b*). The bones adjacent to the zygomaticomaxillary and palatomaxillary sutures of animal A and the zygomaticofrontal and sphenozygomatic sutures of animal B were disarticulated also (Fig. 8). In contrast, the zygomaticomaxillary suture of animal B appeared to be compressed (Fig. 8, *b*). The pterygomaxillary fissures were enlarged.

Changes in bone morphology also were evident. The maxillary and zygomatic bones of both animals were altered considerably in form compared with the control dry skull and with each other. The adjacent bones were affected also, especially near their sutural borders. No apparent changes were evident in the dentoalveolar complexes as a result of force application. Skeletal changes, however, produced significant changes in interarch dental relationships (Fig. 10, *b*).

Mobility and inflammation

All of the titanium implants were immobile when the abutments were placed. The facial implants remained immobile throughout the experimental period. The abutments of these implants occasionally became loose, but were tightened easily with a screwdriver.

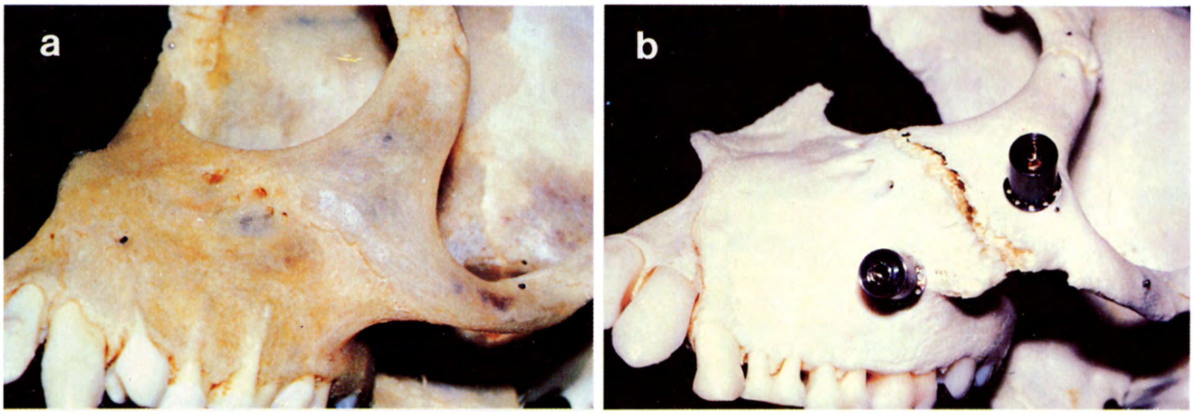


Fig. 9. Dry skull preparations showing the zygomaticomaxillary sutures from an experimental animal in which a protraction force was applied to the teeth **(a)** and experimental animal A **(b).** When a protraction force was applied only to the teeth **(a),** the gross sutural response was negligible. When the protraction force was applied directly to the maxillary titanium implant **(b),** the zygomaticomaxillary suture was nearly disarticulated. (Part **a** from Jackson GW, Kokich VG, Shapiro PA. AM J ORTHOD 1979;75:318-33.)

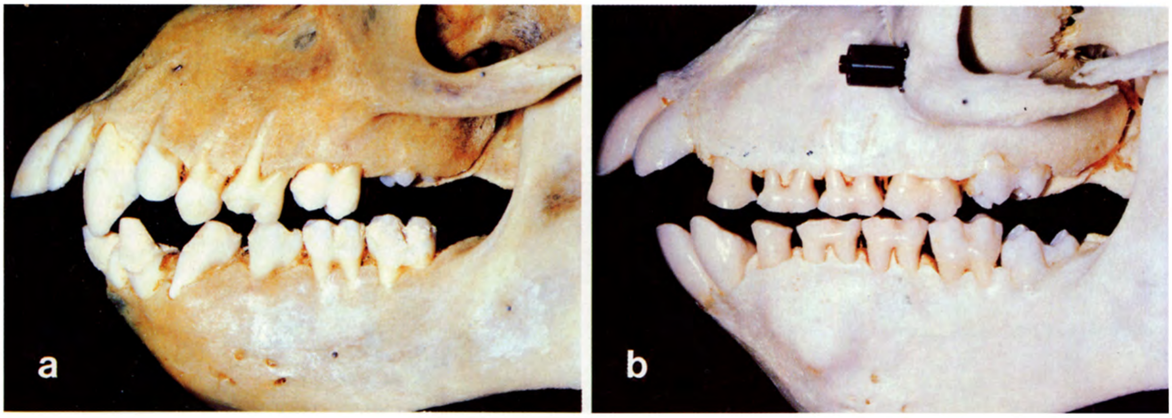


Fig. 10. Dry skull preparations showing the dental effects of maxillary protraction in an animal in which the protraction force was applied to the teeth **(a)** and experimental animal B **(b).** When a protraction force was applied directly to the dentition **(a),** the teeth tipped significantly in a mesial direction. When the protraction force was applied to the zygomatic titanium implant **(b),** the entire maxilla was moved anteriorly with no dental compensation. (Part **a** from Jackson GW, Kokich VG, Shapiro PA. AM J ORTHOD 1979;75:318-33.)

Mild inflammation was chronically present around the abutments during the study and became worse when abutments loosened. The status of the cranial implants was difficult to assess after the frameworks of the extraoral traction appliances were attached.

Histologic and radiographic analyses of implants

The specimen containing the implant from the right zygomatic bone of animal A was not used for force application. Histologically the specimen had mature bone tissue in contact with the implant along most of its titanium surface. Few signs of inflammation were detected. In the other specimens, bone was also in contact with the titanium surface but not along the entire surface (Fig. 11). Few inflammatory cells were seen in the connective tissue adjacent to the superficial proximal part of the implants. Radiographic analysis showed bone with a normal trabecular pattern adjacent to the implants. No obvious radiolucencies were apparent around the implants.

Histologic analysis of sutures

The zygomaticotemporal sutures of the control and animals B and C were evaluated histologically. The

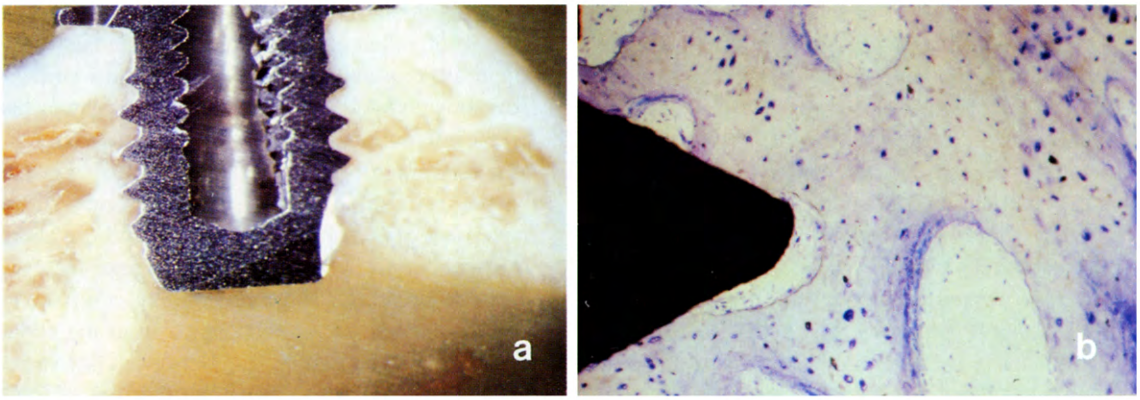


Fig. 11. Cross-sectional views of the zygomatic titanium implant from experimental animal B. **a,** Gross view showing the intimate relationship between the threaded implant and the adjacent bone. (Original magnification ×10.) **b,** Microscopic view showing bone in direct contact with the titanium surface of the implant. (Original magnification ×250.)

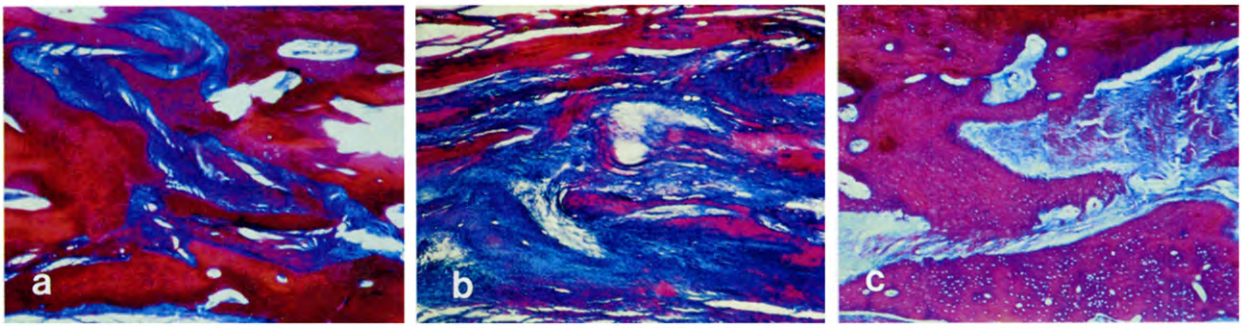


Fig. 12. Photomicrographs of the zygomaticotemporal sutures from the control animal **(a)**, the experimental animal B **(b)**, and the experimental animal C **(c)**. After protraction **(b)**, the suture was much wider than that seen in the control animal **(a)**. In animal C **(c)**, the suture was allowed to relapse for 18 weeks, resulting in a narrowing of the sutural space. (Original magnification ×48.)

suture from animal B (killed at the end of the protraction period) was much wider than the sutures from the other two specimens (Fig. 12). In addition, the sutural bony margin from animal B was irregular with long spicules extending into the widened sutural space. The collagenous sutural fibers were stretched but continuous between the temporal and zygomatic bony surfaces. Microscopically the suture from animal C (18 weeks of relapse after protraction) was narrower than the suture from animal B but slightly wider than the control zygomaticotemporal suture (Fig. 12). Furthermore, the sutural bony margin from specimen C was less irregular with short spicules, resembling the sutural morphology seen in the control specimen.

DISCUSSION

This investigation has shown that titanium implants placed in the maxillary and zygomatic bones of young, nonhuman primates provide stable anchorage for protraction of the facial bones. Adell and associates[19] found that it was impossible to move titanium implants placed in the jaws of dogs by varying either the magnitude or direction of orthodontic force. Roberts and associates[10] reported similar findings when they continuously loaded commercially pure titanium screws that had been acid-etched and implanted into the femurs of rabbits. Although others[7,8] have demonstrated that various types of implants remain immobile when loaded, none appear to offer the stability and reliability of osseointegrated titanium implants. In view of the present findings and those of others, titanium implants appear to offer a reliable means for applying forces directly to bones to produce changes in their form and position.

Protraction of the facial bones was accomplished by remodeling of the circummaxillary sutures and bony surfaces. The greatest amount of remodeling occurred in those sutures and bones closest to the force application. Previous investigators[3,25,26] who have relied on teeth for the application of force have reported similar findings with maxillary protraction. However, none have demonstrated the magnitude of skeletal remodeling that was observed in this study. Reliance on the teeth for force application often results in undesirable dental changes. Jackson, Kokich, and Shapiro[3] reported significant dental tipping from the application of anteriorly directed extraoral force to tooth-borne splints in *Macaca nemestrina* monkeys. No significant dental changes were observed in this study. These results indicate that extraoral force may be applied to osseointegrated implants in the facial bones to avoid undesirable dental side effects.

The present investigation showed that vertical changes associated with anterior displacement of the maxillary complex could be controlled by changing the direction of force applied to the osseointegrated implants. Kambara[25] and others[3,26] reported counterclockwise rotation of the maxillary complex during maxillary protraction in monkeys using tooth-borne anchorage. Anterosuperior movement of the maxillary complex was also observed in the present study. However, as the direction of force was changed by moving the anterior bar of the extraoral appliance inferiorly, the superior component of movement was decreased or eliminated. These results indicate that the direction of maxillary protraction can be controlled.

The experimental results of this study were relatively stable. The maxillofacial complexes of both animals C and D relapsed about 20%; almost all of the relapse occurred during the first 2 weeks. In the case of animal D, it is believed that the relapse occurred during the transition from removal of the traction springs to placement of retaining wires. The stability of the skeletal changes was not unexpected since it has been shown previously that skeletal movement is more stable than dental tipping.[2,3] Clearly this study has demonstrated the enormous adaptive capacity of the sutural articulations.

According to Brånemark and others,[14,16,27] osseointegration of titanium implants is dependent on several factors. These include optimal design and surface finish of the implant, healthy bone, a delicate surgical technique with primary closure, and the absence of loading during the healing period. Our implantation technique was performed with these factors controlled. All of the implants were immobile at the time the abutments were placed. At the end of force application, the facial implants remained immobile, although histologically they were not osseointegrated completely.

Brånemark and Albrektsson[28] investigated the conditions required for long-term penetration of human skin by titanium implants. They found that it was necessary to restrict the movement of the skin around the implants to prevent inflammation. Tjellström and co-workers[21] supported this finding in a 5-year clinical study in human subjects. Adell and associates[19] reported that persistent inflammation could lead to progressive marginal bone loss and ultimately to loss of osseointegration. In the present study, no attempt was made to limit the movement of the monkey's skin around the abutments or to control the level of hygiene. These factors probably contributed to the mild inflammation seen clinically and confirmed microscopically in the soft tissue around the facial abutments. However, this inflammation did not adversely affect the stability of the facial implants during the relatively short experimental period of 12 to 18 weeks.

This investigation is the first to successfully protract facial bones with osseointegrated titanium implants used for skeletal anchorage. Although questions relating to the longevity of titanium implants placed under traction remain unanswered, it seems reasonable that osseointegration of titanium implants could be maintained if appropriate measures were taken to control inflammation. The potential application of this technology in the treatment of patients with severe maxillary hypoplasia or other craniofacial abnormalities is great enough to warrant further investigation.

SUMMARY AND CONCLUSIONS

An anteriorly directed extraoral force was applied to titanium implants placed in the maxillary and zygomatic bones of four healthy, young *Macaca nemestrina* monkeys. Experimental, retention, and postretention changes were evaluated cephalometrically, histologically, and grossly. In view of the results obtained, the following conclusions can be made.

1. Titanium implants placed in the facial bones provided stable anchorage for protraction of the maxillofacial complex.
2. Traction applied directly to the maxilla and/or zygomatic bones produced marked movement of the maxillofacial complex anteriorly without significant changes in the dentoalveolar complex.
3. Movement of the facial bones was accomplished through skeletal and sutural remodeling.
4. Eighty percent of the skeletal movement was maintained 22 weeks after the applied traction was removed.

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