The effect of bite-blocks with and without repelling magnets studied histomorphometrically in the rhesus monkey (Macaca mulatta)

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The effect of bite-blocks with and without repelling magnets as proposed for the treatment of open bite was analyzed. Twelve male juvenile monkeys were divided into three groups of four. Group A was used as control, group B was given bite-blocks containing samarium cobalt disks, and group C received identical bite-blocks without active magnets. The monkeys were observed for 24 weeks before death. Histomorphometric evaluation was then performed on the molar roots, their periodontal tissues, the zygomaticotemporal suture, and the pterygomaxillary suture. The root surfaces of the molars in both the bite-block gorup and the magnetic group were characterized by pronounced resorption that sometimes was active and occasionally undergoing repair with bony tissue. The sutures also clearly reflected the effect of both appliances used, although more markedly in the cases of bite-blocks containing active magnets. The surface density expressing the sutural area, was increased significantly, possibly as an adaptation to the altered functional demand. The cellular activity of the sutural surfaces also was increased markedly in both appliance groups, reflecting an ongoing adapation. A steady state had not been reached. The study demonstrated a widespread effect of the force developed by bite-blocks with and without magnets. The final quantity and the reversibility of the effect is not known, however. More long-term studies should be undertaken to obtain this information. (AM J ORTHOD DENTOFAC ORTHOP 1995;108:500-9.)

Although it was once thought that anterior open bite was related to a short mandibular ramus,[1] it is now generally recognized that anterior open bite is highly related to excessive development of the molar region, leading to a posterior rotation of the mandible.[2-6] Both surgical and nonsurgical approaches to treatment have been advocated, depending on the severity of the existing malocclusion, the degree of skeletal development, and the age of the patient.

Differing perceptions of the form-function relationship have resulted in varied approaches to the nonsurgical treatment of anterior open bite. One group of authors,[7-10] has advocated restriction of the tongue space, since they feel that hypermobility of the tongue was causing the open bite. With the same basic philosophy, they recommended speech therapy as part of the treatment regimen. Still focusing on the tongue and its volume, surgical reduction of the tongue also has been recommended.[11-14]

Another approach to treatment is based on the assumption that function is secondary to structure. Thus, such investigators as Speidel et al.[4] and Profitt and Mason[15] have recommended orthodontic treatment of the existing malocclusion as the primary therapeutic procedure. In addition, Pearson[16] recommended the use of extraoral traction, by using a high-pull chincup to produce posterior intrusion of the dentition as part of the orthodontic treatment.

A recent approach that has been advocated for the nonsurgical treatment of open bite is the use of the active vertical corrector, an appliance characterized by repelling magnets placed in bite-blocks that cover the posterior teeth.[17] Dellinger[17] indicated that closure of the anterior open bite may be enhanced by one or more of the following modes of action: (1) the constant intrusive force delivered by the active vertical corrector (AVC), (2) the increased cellular activity that occurs when tissues are subjected to time-varying magnetic field and "that the possibility of microcurrent flow should be considered a positive tissue stimulator" with saliva acting as an electrolyte. The last effect, however, is questionable as saliva can also be

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thought of as a short circuiting environment, diminishing any bioeffect.

Kalra et al.[18] examined the treatment effects produced by repelling magnetic appliances. They reported an increase in mandibular length, intrusion of teeth, and an upward and forward autorotation of the mandible in 20 patients treated with fixed magnetic appliances. Barbre and Sinclair[19] reported maxillary and mandibular molar intrusion and autorotation of the mandible in 25 open bite cases treated with the active vertical corrector appliance. However, they noted only minimal skeletal changes in the sagittal direction.

The effect of opening the bite vertically, with posterior bite-blocks, must be differentiated from the effect of bite-blocks that contain repelling magnets. A series of experimental studies in monkeys considered the effect of opening the vertical dimension with bite-blocks without magnets.[20-24] Cast onlays were used to open the bite posteriorly. The adaptation to the appliance by the experimental animal involved the temporary lengthening of the masseter and other elevator muscles. In juvenile animals, the most striking and consistent finding was a marked reorientation of the growth of the entire midfacial complex. The growth of the midface was directed anteriorly and markedly superiorly. This superior and anterior displacement of the maxilla was most noticeable in the premaxillary region.[22] Adaptations were also observed in the growth of the mandible. The bite opening splints were found to decrease the downward growth of the mandible, while the anterior growth was increased slightly.[22] These observations also were reported by Kalra et al.,[18] who perceived this mandibular growth change as a result of stimulated condylar growth.

Varied results have been reported in the literature regarding the relative intrusion of the posterior teeth, after bite opening with nonmagnetized splints in experimental animals. McNamara[20] reported no intrusion of the maxillary or mandibular teeth, although the eruption of these teeth was apparently inhibited by the appliance. In contrast, Altuna and Woodside[25] have reported considerable depression of the maxillary molars in a similar experimental model. Recently, Darendeliler and Joho[26] presented a removable appliance with repelling magnets posteriorly and attracting magnets anteriorly, but they did not report any results.

Another cephalometric study by Hoenie[27] was designed with the purpose of separating the effect of the magnets from that of the bite-block in the rhesus monkey. Three groups of four juvenile monkeys were analyzed, one group serving as controls, one group receiving maxillary and mandibular bite opening splits, containing nonmagnetized samarium-cobalt magnets and the last group receiving identical splints containing the same rare earth magnets that were energized to saturation. The findings from the nonmagnetized group were similar to the studies discussed previously. The introduction of the energized repelling magnets gave rise to unexpected changes in the transverse dimension, with skeletal asymmetries being produced in three of the four animals studied. This lateral shearing effect of repelling magnets has now been eliminated by Dellinger, who has redesigned the acrylic bases of the vertical corrector with restricting acrylic flanges. True dental intrusion of the buccal segments could not be shown in any of the two bite-block groups. The observed changes were related to skeletal rather than dentoalveolar adaptations. When Kiliaridis et al.[28] compared the effect of magnets and bite-blocks on open bite in 20 patients, no evidence of clinical significant molar intrusion was presented. Although there was an improvement in the severity of the open bite, asymmetries corresponding to those described by Hoenie[27] developed in several of the patients.

Magnetic forces were introduced in orthodontics by Blechman and Smiley,[29] who performed a clinical and radiographic study of intramaxillary magnets in cats. Postmortem analysis of the cats revealed no pathologic findings, although the authors warned that lengthy treatment might result in periodontal disturbances and root resorption. Blechman[30] later reported on the clinical results of both intramaxillary and intermaxillary samarium-cobalt magnets. However, only a few studies have analyzed the possible biologic effect of magnetic fields. Linder-Aronson and Lindskog[31] reported that the effect of a static field was a significant increase in resorbing areas underneath magnets that had been fixed to the tibia of young rats. They suggested that the resorption activity was related to an inhibition of the developing osteoblast, i.e., an uncoupling.[32] The effect seemed to increase with time over the 4-week observation period and was present both in cases of repelling and attracting magnets. The design of this study was, however, greatly criticized in letters to the editor, in which further research in the area was encouraged.[33,34] A more recent study on the effect of a static magnetic

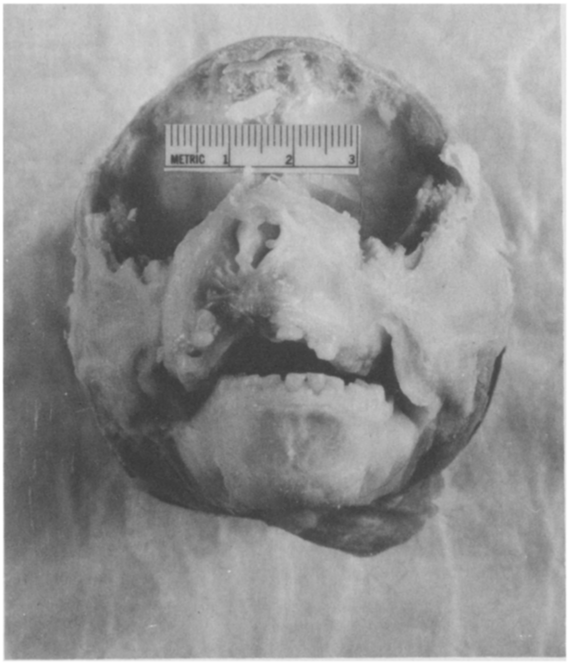


Fig. 1. Microscopic field with superimposed test system. Surface density is estimated from intersections between cycloides and bony surface.

field does, indeed, fail to demonstrate any long-term effect of a magnet placed over the sagittal suture.[35] A comparison of the biologic effect of the magnets is, however, not simple as there is a large variation in both force magnitude, flux density, and materials used in the articles cited.

Repelling magnets that are incorporated in appliances used in the treatment of open bite are usually worn for an extended period of time and the tissue reaction and any potential iatrogenic response to this appliance is therefore of considerable interest.

The purpose of this report was therefore to perform a histomorphometric analysis of the molars, their periodontal tissue, and the temporal-zygomatic and pterygomaxillary sutures in monkeys wearing magnetized and nonmagnetized bite-blocks. The results of these studies are compared with a matched control popuplation. The monkeys had been previously studied cephalometrically by Hoenie.[27]

MATERIALS AND METHODS

Sample

Twelve male juvenile rhesus monkeys *(Macaca mulatta)*, obtained from the Caribbean Primate Research Center in Puerto Rico, were used in this study. The animals were divided into three groups of four and were comparable with regard to the stage of dental development. All animals had an intact deciduous dentition and fully erupted first molars. According to the tooth eruption data of Hurme and Van Wagenen,[36] these animals were approximately 18 to 24 months of age at the beginning of the study.

Appliances

Bite opening appliances with magnetized disks in a repelling configuration were inserted in the animals of the first group. Four additional animals were given similar bite-blocks containing samarium-cobalt disks, but these disks were not energized. The last four animals received no appliances and were used as controls.

The splints consisted of bilateral acrylic blocks, connected and reinforced by a 0.036-inch stainless steel framework. Samarium-cobalt disks, covered by stainless steel casings as advocated by Dellinger,[17] were imbedded in each block. To produce repelling forces, the polarity of the maxillary and mandibular magnets was the same. The stainless steel casings containing the magnets that were provided by Active Vertical Corrector Inc. had a diameter of 5 mm and a vertical height of 2 mm. Every effort was made to place the metal disks in positions that minimized the vertical opening produced. The magnets were adapted to the size of the monkeys and had a peak repelling force of 358 gm at 0 mm air gap. This force level was, however, never reached even when the monkeys were clenching their teeth because the casings were covered with a thin layer of methacrylate. At 1 mm air gap, the force was 148 gm and at a distance of 2 mm, the magnets were separated by 78 gm of force. When the monkeys occluded, the maximum force was estimated to 250 gm.

Before bonding, the acrylic appliances were equilibrated to allow a balanced occlusion in the posterior region. The appliances were then bonded with Excel bonding resin (Reliance Orthodontic Products, Itasca, Ill.).

Histologic analysis

At the end of the treatment interval (24 weeks), the appliances were removed, and final cephalogram was taken, and then the animals were killed with a perfusion of saline, followed by a 10% solution of neutral buffered formalin. The jaws were excised and replaced in the solution of neutral buffered formalin. Tissue blocks comprising the maxillary molars, the pterygomaxillary fissure, and the zygomaticotemporal suture were excised and decalcified in EDTA, before embedding in celloidin paraffin. All sections were stained with hematoxylin and eosin.

The alveolar processes were cut parasagitally in 8 μm thick sections. Ten sections, all including the full extension of the pulp of at least two teeth, were evaluated.

To avoid bias in the quantitation of the sutures because of the anisotrophy of the structures to be evaluated, a stereologic estimation of surface density, which

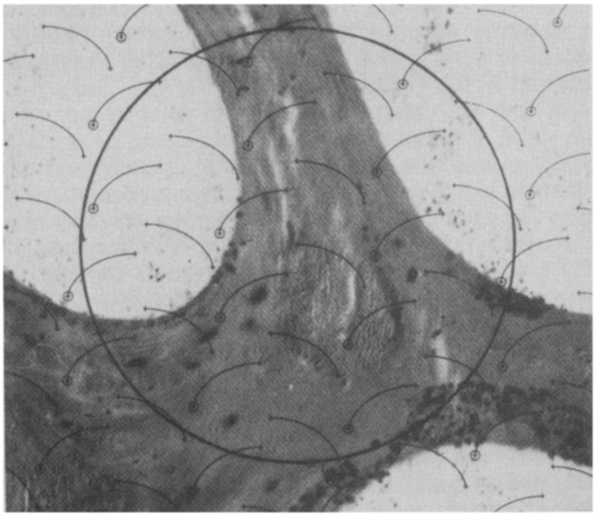


Fig. 2. Photograph of head of one of monkeys in which magnetic appliance had been inserted. Note severe asymmetry. (Courtesy A. Vesterby.)

used vertical sections, was applied. With respect to the suture of the zygomatic arch, the vertical axis plane was defined as being parallel to the long axis of the zygomatic arch that coincided maximally with the bony axis of the zygomatic arch. With respect to the pterygomaxillary region, the vertical axis was defined perpendicular to the occlusal plane. The rotation around this vertical axis was random, as has been described by Vesterby et al.[37] Vertical sections were cut parallel to the cylindrical axis from each specimen; 10 sections that were approximately 200 μm apart were used.

All sections were evaluated in the following way: Five microscopic fields were sampled equidistantly in rows, according to the protocol of Kragstrup et al.[38] An anisotropic cycloid test system, as described by Baddely et al.[39] was used for point and intersection counting. The sections were examined with a projection microscope, by which the microscopic field was projected onto the test grid at a magnification of 100× (Fig. 1). In evaluating the sutures, the stereologic principles were applied in the following way: The axis of the test system was oriented parallel to the vertical axis. The sutural surface density was defined as the total area of the bone surface toward the suture per volume of bone tissue and was calculated as SV = 2I/L, i.e., two times the number of intersection points *(I)* between test lines and sutural surface divided by the total length of the test lines *(L)* (Fig. 1). *L* was estimated as the number of test points *(P)* hitting the reference space multiplied by the know ratio *l/p* between test line length and the number of test points in the integrating system.[40] On average, 200 intersections between test lines and sutural bony surface were counted. Values for *Sv* are expressed in $mm^2/mm^3 = mm^{-1}$.

From the teeth and periodontium, the following parameters were estimated: (1) Relative extending root surface undergoing resorption in permanent teeth erupted and unerupted, expressed by percentages. (2) Relative extension of the alveolar surface facing permanent teeth undergoing resorption by percentage.

Fig. 3. Control monkey. Root surface of one permanent lower molar showing intact surface surrounded by typical periodontal ligament.

From the sutures, the following parameters were estimated: (1) Relative extension of the resorptive, appositional and resting surfaces of the pterygomaxillary suture, expressed by percentage. (2) Relative extension of the resorptive, appositional and resting surfaces of the zygomaticotemporal suture expressed by percentage. (3) Surface density of the sutures of the pterygomaxillary region expressed in mm^2/mm^3. (4) Surface density of the zygomaticotemporal suture expressed in mm^2/mm^3.

The pulp status and the formation of the roots of the permanent teeth considered in this study have been described in a previous publication.[41]

Statistical analysis

The various surface characteristics of the tissues, both within the groups and between groups, were compared with an analysis of variance and the means subsequently compared with a Student-Newman-Keul a posteriori test.

RESULTS

Clinical Evaluation

All monkeys tolerated the bite opening appliances well, regardless of whether the samarium-cobalt disks were magnetized or unmagnetized. Normal weight gain was observed during the experimental period in all animals. Because all the

Table I. Distribution of root and alveolar surface

	Alveolus Relative resorption surface percent	*Root Surface relative resorption surface percent*
Control	11.3 ± 1.5	3.6 ± 1.3
Bite-block	36.1 ± 3.5	17.4 ± 3.4
Magnet	39.9 ± 3.9	21.9 ± 5.2

Table II. Distribution of the parameters, measured in relation to the sutures

	Surface area (mm^{-1})	*Relative resting surface (%)*	*Relative resorption surface (%)*	*Relative apposition surface (%)*
PTM				
Control	2.30	85.86	6.89	13.46
Bite-block	2.54	79.00	8.90	12.08
Magnet	3.00	73.12	10.80	14.50
Zyg				
Control	2.12	89.80	2.70	6.02
Bite-block	2.68	79.60	12.60	15.80
Magnet	2.78	66.30	12.80	20.60

monkeys actively ground the parts of their appliances against each other and also against the bars of the cages, it was occasionally necessary to add acrylic to the metal disks when the exposure of the metal occurred. All the animals developed a pronounced gingivitis in relation to the gingival margin of the appliances.

Three of the four animals that wore a magnetized bite opening appliance developed a significant asymmetrical mandibular jaw posture and asymmetrical wear pattern (Fig. 2).

Histomorphometric evaluation of the root surface

The histomorphometric quantitation revealed that significant treatment effects were produced through the use of both appliance systems, although the tissue response was more pronounced in those animals that wore magnetized splints. In the control animals, 11.3% of the alveolar surface and 3.6% of the root surface were undergoing resorption at the time of death (Table I) (Fig. 3). In contrast, more than a third of the alveolar area in the magnetized and unmagnetized animals showed active bone resorption (Table I). Similarly, significant increase in root resorption were noted in the magnetized (21.9%) and nonmagnetized (17.4%) animals. No statistical difference could be observed between the experimental groups. The areas of root resorption were evenly distributed along the root surfaces. However, those teeth that were tipped against each other showed apical resorption in the contact areas of the roots (Figs. 4 and 5).

Analysis of the periodontal ligament

The histologic analysis of the periodontal ligament revealed that the teeth had been tipped in several cases in both the bite-block and the magnet group. This tipping lead to a complete compression of the periodontal ligament, which in some instances appeared to have resulted in ankylosis, with bone ingrowth in a previously established resorption cavity on the root surface (Fig. 5, *B*).

Sutural surface density

An increase in sutural surface density was seen in the pterygomaxillary and zygomaticotemporal sutures in the animals that wore unmagnetized bite-blocks in comparison to controls (Table II) (Figs. 6 to 11). The animals that wore magnetized bite-blocks showed a response similar to the nonmagnetized group in the surface density of the zygomaticotemporal suture, but showed a more pronounced response in the pterygomaxillary fissure. In both experimental groups, there was a relative increase in the resorptive and appositional surfaces of the sutures, in comparison to controls, with a greater response evident in the magnetized group.

DISCUSSION

Previous studies of bite-blocks with and without repelling magnets have indicated several treatment

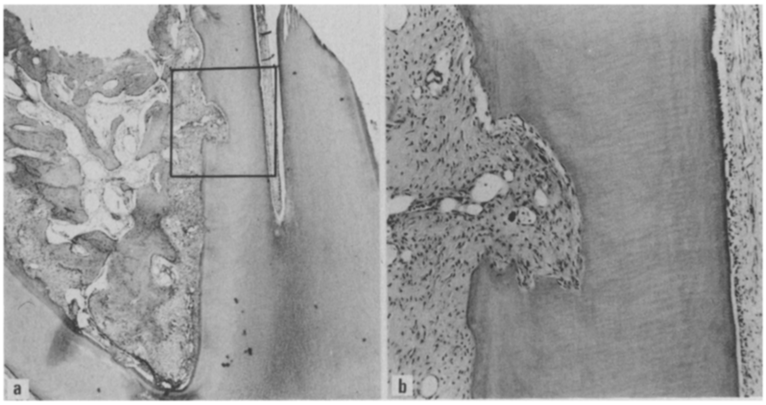


Fig. 4. Bite block monkey. **A,** Root surface of one permanent lower molar characterized by pronounced resorptive activity. **B,** Larger magnification of resorptive area.

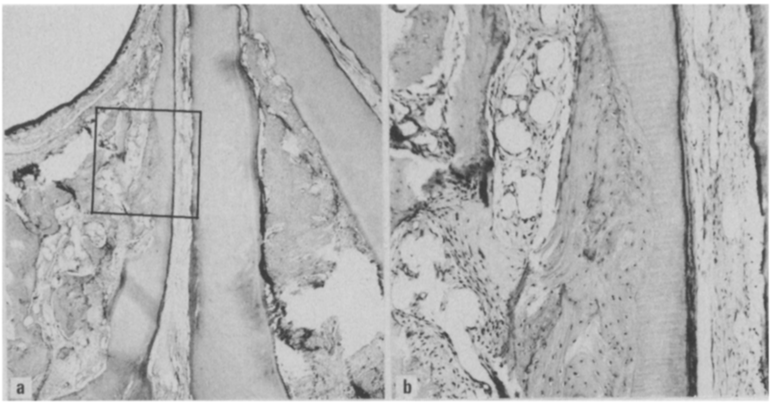
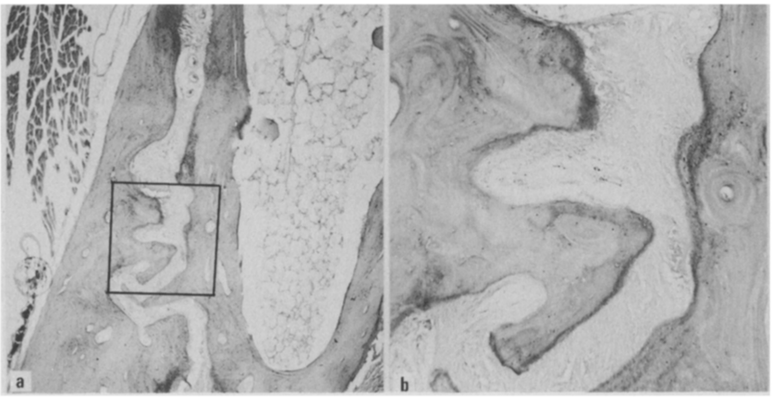


Fig. 5. A, Magnet monkey. Root surface from one permanent lower molar characterized by resorption as well as anchylosis. **B,** Larger magnification of area with bone in growth in previous resorption cavity.



Figs. 6 through 8. (**b** always larger magnification of **a**) Temporozygomatic suture of control (Fig. 6), bite-block (Fig. 7) and magnetic monkey (Fig. 8). Note difference in orientation and complexity and suture between control and treated monkeys.

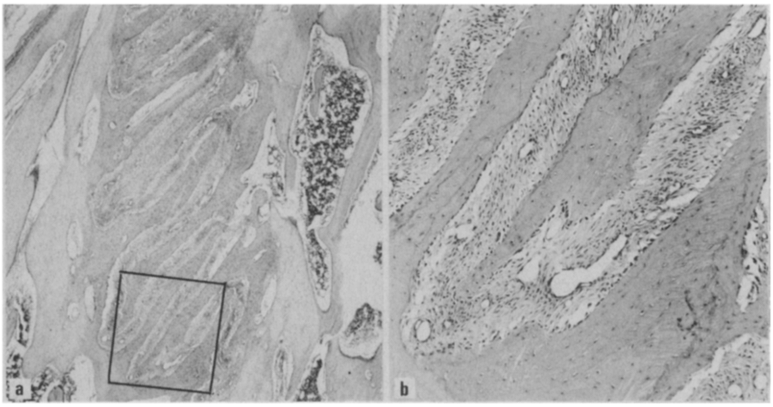


Fig. 7

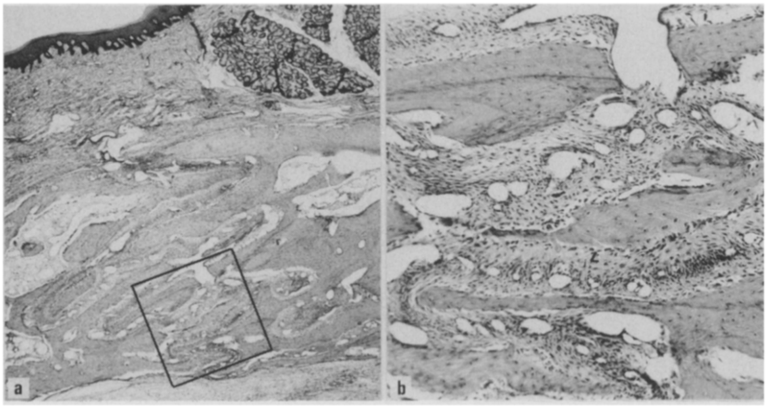
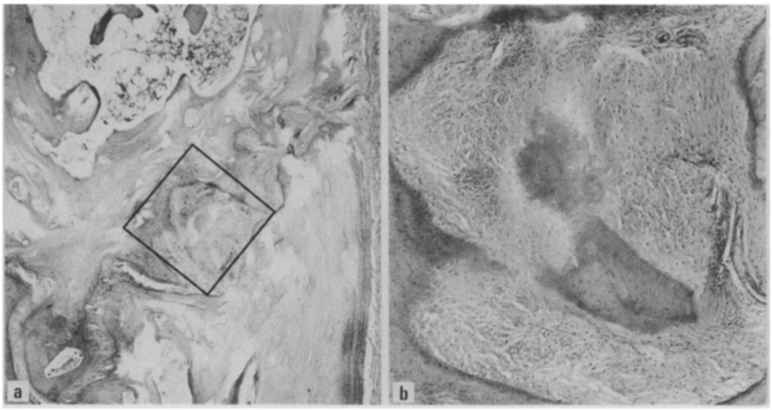


Fig. 8



Figs. 9 through 11. Pterygomaxillary region in control (Fig. 9), bite-block (Fig. 10), and magnetic monkey (Fig. 11). Note difference in complexity and activity specially visible in larger magnification.

effects produced by these appliances. These effects include the restraint of the vertical development of the maxillary complex as a well as molar intrusion.

The results reported by various authors do not attribute the same weight to skeletal and dentoalveolar changes. In studies of nonmagnetized bite-blocks, Bosscher[42] and Woods and Nanda[43] report only limited dental intrusion and McNamara[20] noted an inhibition of eruption but a lack of actual intrusion in his study. Altuna and Woodside,[25] on

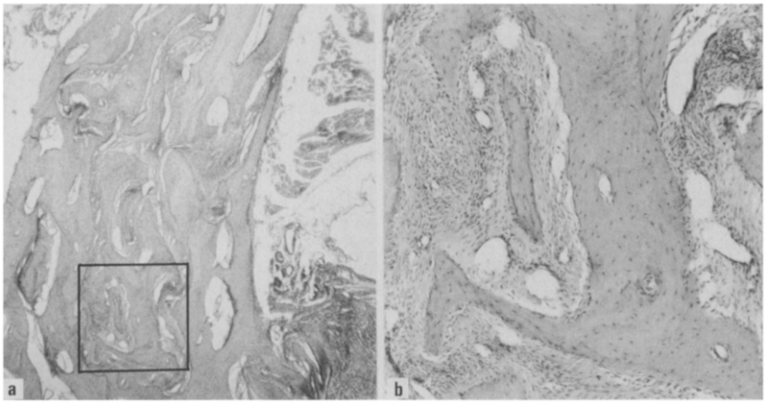


Fig. 10

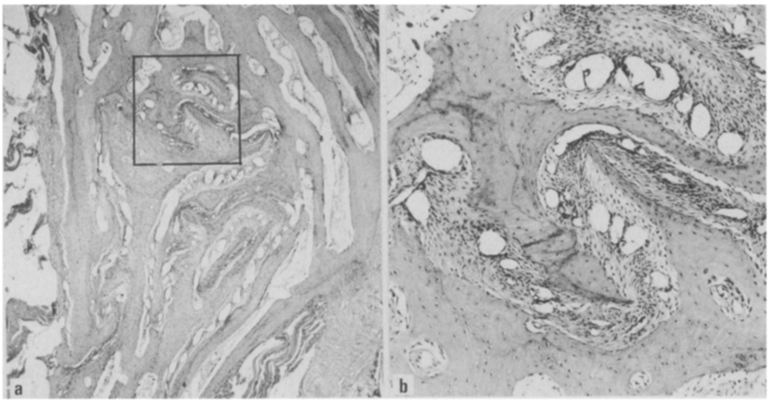


Fig. 11

the other hand, showed considerable molar intrusion. Because these studies were performed in monkeys, these differences in response may be due to variations in the stage of dental development and in the magnitude of the forces exerted by the appliances, as well as differences in placements of the magnets. Further, the lack of specification of the magnets makes it difficult to compare the different studies. The monkeys used in this study were 18 to 24 months of age, which corresponds to the age range in which Dellinger[17] is treating his patient and to the age of the animals studied by Barbre and Sinclair[19] and Woods and Nanda.[43]

A clear differentiation between the effect of the bite-block itself and the magnets is difficult, as is the evaluation of the force system developed since the individual monkeys were left to function on the bite-blocks at their leisure. This is also the case with patients treated with the AVC.[18] Only in case of intramaxillary magnets could the forces developed be established in detail.

In this study, increased resorptive activity was provoked by the use of both unmagnetized and magnetized bite-blocks. Intrusive forces as produced by the appliances used in this study, have previously been related to resorption, but these studies have been performed on incisors.[44-47] Among other factors that may be of importance in the explanation of the observed tissue reaction are the force magnitude, the duration of treatment, and the traumatic occlusion[46] should be mentioned. In this study, the precise nature of the forces produced is not known, since they occur as an interaction between muscle force and the repelling force generated by the magnets. Although the exact magnitude of the force is not known, it can be expected to exceed the level of force generally developed by an intraoral orthodontic appliance, although similar forces may be applied through extraoral traction. The tissue reaction to such appliances has, however, not been studied histomorphometrically.

An important finding in relation to the magnetized bite-blocks was the development of asymmetries, as a result of the shearing effect of approximating repelling magnets and possibly of the monkey trying to avoid the strong repelling force. The shearing effect may also contribute to the histologic results. Asymmetries were observed in several of the patients studied by Kalra and Burstone,[18] and by Kiliaridis et al.[28] It is therefore important that this be avoided through construction of the appliance so that lateral movements are limited by the addition of lateral flanges, restraining lateral movements.

The reaction of the suture in both bite-block groups in comparison to controls is a clear indication of the adaptation occurring to the changes in mechanical stimuli. The more pronounced activity seen in the magnetic group may be caused by the magnets or may in part be explained by the shearing effect of the approximating repelling magnets. The asymmetrical forces generated through the wearing of the magnetic appliances may have produced a traumatic occlusion and possibly bruxism, factors that also contribute to the resorption.[46]

The stereologic method used in this study made it possible to express the sutural area in absolute area per cubic millimeter. It was obvious that the surfaces of the sutures not only became more complicated in the treated animals, but that the cellular activity level increased, indicating areas of bone remodeling. Such remodeling is always a sign of the sutures adapting to a change in functional demand. Such a change may be reflected both in the main direction of the suture and in surface density. An increase in surface density may result in a decrease in strain over the sutural tissue; under certain conditions, the same type of response may also be obtained by a change in orientation of the suture. Because no valid quantitational method is available for the determination of orientation of the structures defining the sutures, such an evaluation can only be subjective in nature.

Because of the overall high level of osteogenic activity in the sutures at the end of the 24-week experimental period, it can be assumed that the sutures were still in a transitional state.[32] It can be anticipated that, given a longer treatment period, there would have ultimately been a return to an equilibrium in which the neuromuscular pattern and the craniofacial structure would have adapted to the alteration in the vertical dimension.

CONCLUSION

In conclusion, the results of this study, as well as the previous study on root formation,[41] indicate that a number of treatment effects are produced by bite-block appliances, both with and without magnetized disks imbedded in them. Treatment effects include skeletal changes, particularly in the maxillary region as well as dentoalveolar adaptation. The skeletal changes include remodeling in both the pterygomaxillary suture and in the zygomaticotemporal suture. Evidence of root resorption and ankylosis has also been shown.

Because of the limited duration of this study (24 weeks) and because the tissues involved were still undergoing active remodeling, no conclusion can be reached regarding the exact nature of the cellular reaction over the long term, after neuromuscular and skeletal balance has been reestablished.

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