The Influence of Controlled Occlusal Overload on Peri-implant Tissue: A Histologic Study in Monkeys

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This study examined the influence of controlled occlusal overload on an implant. An experiment was conducted on five crab-eating monkeys (*Macaca fascicularis*) in which overload with no inflammation in the peri-implant tissues was modeled. Two osseointegrated implants were placed into each monkey. After 3 months of osseointegration, superstructures that were excessive by about 100 μm were mounted on the implants, and a traumatic occlusal force was experimentally delivered to its implant from the lingual to the buccal side. This procedure was performed under conditions of good oral hygiene. The monkeys received an excessive occlusal force for 1 to 4 weeks and were then immediately sacrificed. The results showed that the implants remained firmly integrated with bone, and all of the subjects that received excessive occlusal force for 1 to 4 weeks showed an absence of gross bone loss. These results suggest that conditions of occlusal force created by excessively high implant-supported superstructures may not destroy the peri-implant tissues.
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Key words: histologic study, occlusal overload, osseointegrated implant

The root-form osseointegrated implant, which was first clinically described in 1965 by Brånemark, has been based on detailed basic research and product control since its early development.[1,2] Such efforts have made implants an attractive treatment modality for replacing missing teeth, leading to a rapid increase in their use. However, as the use of endosseous implants has expanded, an increasing number of failures have been reported.[3–7] Most of these involve peri-implant bone resorption and defects, and many are accompanied by periodontal problems. Few periodontal studies have been conducted on inflammation in the peri-implant tissues and implant response to overloading. It has been shown that plaque accumulation can result in inflammation in the peri-implant mucosa and marginal bone loss around the implant.[8,9] Studies of implant overloading have demonstrated loss of the marginal bone or complete loss of osseointegration.[10–12] In recent experimental studies of implant overloading in monkeys, loss of implant osseointegration was demonstrated.[13,14] The present study used crab-eating monkeys for the preparation of a primary occlusal trauma model, in which controlled excessive occlusal force was delivered to the implants. Following application of the force for various periods of time, the animals were sacrificed and their peri-implant tissues were examined histopathologically.

Materials and Methods

The experimental animals were five male crab-eating monkeys (*Macaca fascicularis*), each approximately 2 to 3 years of age and weighing 2.7 to 3.7 kg. The monkeys were kept in separate metal cages under constant temperature and humidistat conditions (28 ± 1°C, 50% to 60%) with sufficient solid monkey food (Japan Clea Company, Tokyo, Japan) and tap water. The oral hygiene procedures were performed once a week under general anesthesia to maintain the

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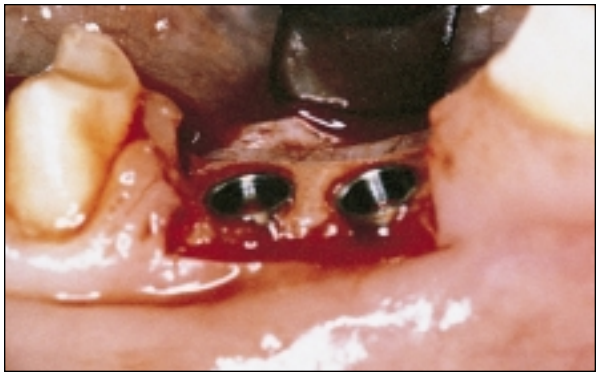

Fig 1 Three months following tooth extraction, two experimental IMZ implants were placed parallel to each other.

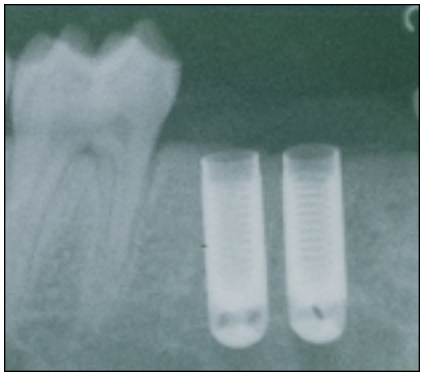

Fig 2 Radiograph taken 3 months after the first surgery.

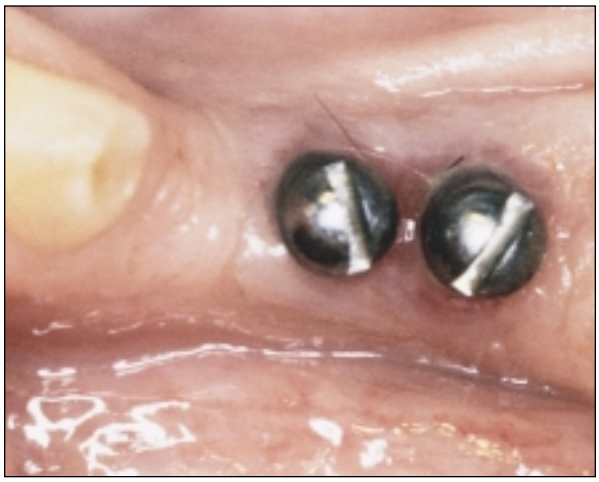

Fig 3a After the second surgery, the site was left for 2 weeks to recover.

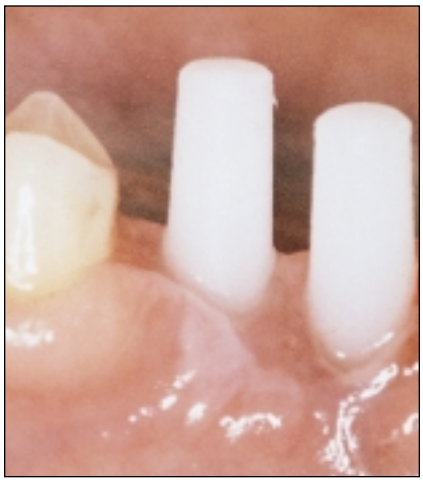

Fig 3b Impression posts used to obtain an impression for the superstructure.

periodontal tissues in as healthy a condition as possible. The test sites were the second premolar and the first molar teeth in the right mandible. The implant used was an experimental IMZ implant supplied by Friatec (Mannheim, Germany) that measured 2.8 mm in diameter and 8 mm in length.

The monkeys were preanesthetized with an intramuscular injection of a mixture of 0.1 mL per kg of atropine and 0.05 mL per kg of Ceractal (Bayer, Mannheim, Germany). Fifteen minutes later, general anesthesia was induced with an intramuscular injection of 0.15 mL per kg of ketamine hydrochloride. The second premolar and the first molar in the right mandible were extracted under local anesthesia with 2% lidocaine, including epinephrine for hemostasis. After 3 months of bone healing, the extraction sites were macroscopically and radiographically examined; they demonstrated no abnormality. Full-thickness mucoperiosteal flaps with vertical releasing incisions were raised, and two implants were placed in the edentulous area nearly parallel and to the crest of the alveolar ridge according to the instructions given by the manufacturer (Fig 1). The surgical wounds were closed and sutured.

The implants were left covered for 3 months to allow them to integrate with the bone. Upon examination, the test sites showed no signs of inflammation, and radiographs confirmed the absence of bone resorption (Fig 2). The implants were then uncovered in a second surgery according to an established method.[15] After the second surgery, the sites were left to recover for 2 weeks (Fig 3a). An impression was made using a standard plastic impression post (Fig 3b), and the impression post was cast in gold-silver palladium alloy (GC Dental Industrial, Tokyo, Japan) for the abutment.

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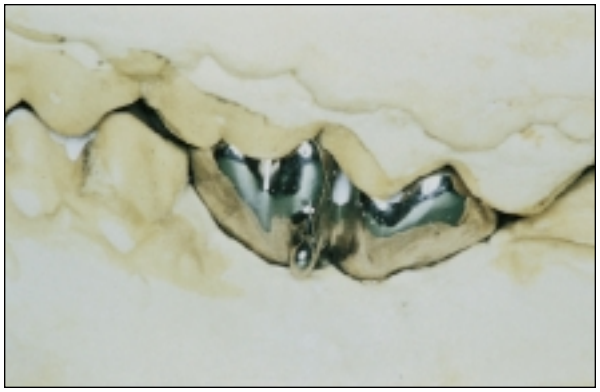

Fig 4 The superstructures were prepared on the master cast.

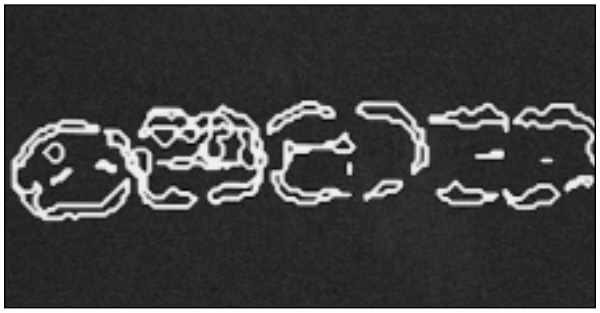

Fig 5 The superstructures were designed so that a lateral force could be applied from the lingual to the buccal side.

The cast abutment was attached to the implant, and an impression was made for a superstructure. The superstructure was fabricated so that a lateral force from lingual to buccal could be applied at the intercuspal position (ICP) (Fig 4). Initially, an occlusal record of the ICP was made using black silicone on the master cast. Then the occlusal surface of the superstructure was designed by an image-analyzing system (according to the technique developed by Miyata[16]) to be excessive by about 100 µm at the time a lateral force from lingual to buccal (Fig 5) was applied. After the impression was obtained, the test sites were again left to recover for 1 week, at which time they were deemed to have no inflammatory symptoms or peri-implant bone resorption. The completed superstructure was then cemented, and an occlusal record obtained with black silicone was used to confirm the quantity of excessive height.

The monkeys were identified according to their occlusal-force loading periods: model A, control (no occlusal force); model B, 1-week occlusal-force loading; model C, 2-week occlusal-force loading; model D, 3-week occlusal-force loading; and model E, 4-week occlusal-force loading. The mandibles were removed under general anesthesia after an excessive amount of ketamine hydrochloride had been intraperitoneally administered. The animals were sacrified according to the animal experimental guidelines of Meikai University after the periods specified above. A catheter was inserted into the common carotid artery for perfusion with physiologic saline solution, and then perfusion fixation was performed according to an established method.[17] After the perfusion fixation was completed, the test site was removed to prepare a block that included the implants. The block was fixed with 10% neutral formalin to avoid decalcification. An abrasion sample was then prepared according to an established method and dyed with

Fig 6 A measurement of the quantity of bone resorption around the implant was made using a computer image analyzed into a digital format and then analyzed by NIH image. A slide specimen was measured from point A to point C and from point A to point B for each lingual and buccal surface.

Cole's hematoxylin-eosin for microscopic examination.[18] A measurement of the quantity of bone resorption around the implant was made using computer image analysis. A slide specimen was scanned by a 35-mm film scanner (Nikon LS-1000, Coolscan, Tokyo, Japan) into a digital format and was analyzed by NIH image (version 1.62; National Institutes of Health, Bethesda, MD). A converted slide specimen was measured from point A to point C and from point A to point B at each lingual and buccal surface (Fig 6). The measured value on the image was converted into an actual survey value. The actual survey value

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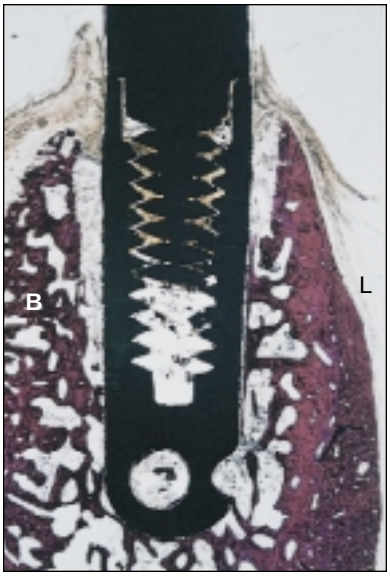
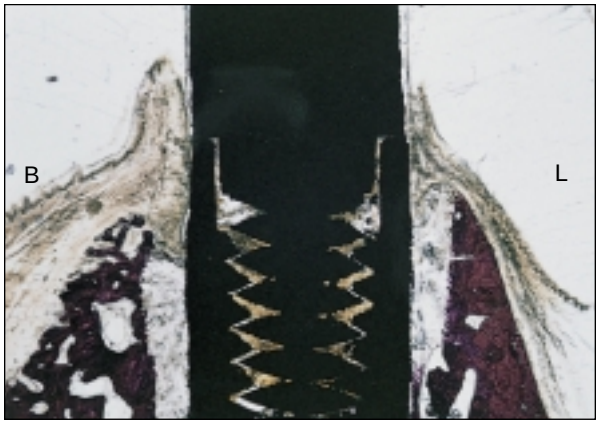
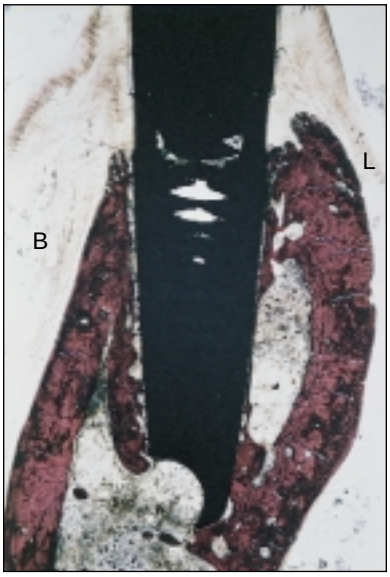


Figs 7a and 7b Histopathologic observation (control): most of the surface of each implant was well integrated with the bone, without obvious bone resorption around the implant. Fig 7a: Original magnification × 10. Fig 7b: Original magnification × 30.





Figs 8a and 8b Model B (1 week occlusal-force overloading): the quantity of bone resorption was 1.90 mm at the lingual (L) and 1.20 mm at the buccal (B). Fig 8a: Original magnification × 10. Fig 8b: Original magnification × 30.

Table 1 Quantity of Bone Resorption Around the Implants

	Bone resorption (mm)	
Model	Lingual	Buccal
A (control)	1.62	1.16
B	1.90	1.20
C	1.76	1.21
D	1.67	0.86
E	1.66	1.18

Table 2 Means and Standard Deviations of the Excessive Overload Group*

Site	Mean (mm)	SD (mm)
Lingual	1.74	0.111
Buccal	1.11	0.149

*Four subjects from models B to E.

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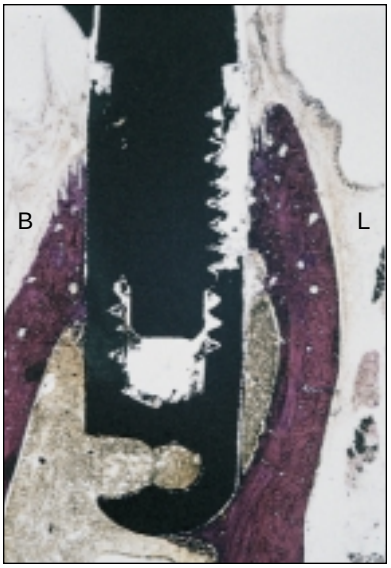

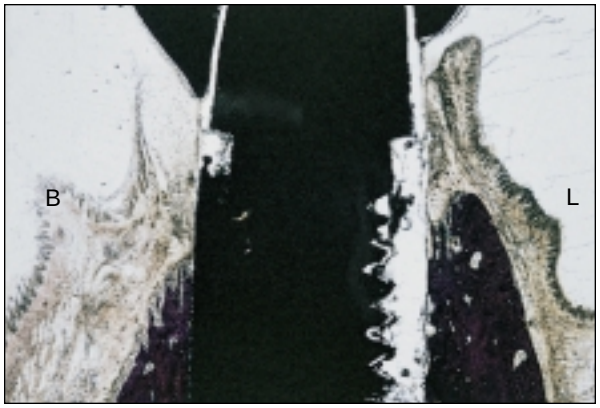

Figs 9a and 9b Model C (2 weeks occlusal-force overloading) shows reasonable integration of bone around the implant. Likewise, the quantity of bone resorption was approximately the same as the control. Fig 9a: Original magnification × 10. Fig 9b: Original magnification × 30.

could be obtained by taking the measured length from point A to point C and dividing it by 8.0 mm, which is the length of the experimental implant. This obtained numerical value is a coefficient of revision of the actual survey value. Accordingly, the actual quantity of bone resorption could be obtained through measured value from point A to point B on the image multiplied by the coefficient of revision.

Results

None of the specimens showed inflammatory symptoms, such as redness or swelling, looseness of the implants, or damage or breakage of the superstructure, at the end of the experimental periods. All implants were well integrated with the bone, although their plasma-jet flame–coated surfaces showed partially different dyes. Table 1 gives the results of the quantity of bone resorption at each implant. Model A (control) showed 1.62 mm at the lingual and 1.16 mm at the buccal. The mean values of the four occlusal-force loading subjects was 1.75 mm (SD 0.11 mm) at the lingual and 1.11 mm (SD 0.15 mm) at the buccal (Table 2).

Most of the surface of each implant was well integrated with the bone, without obvious bone resorption around the implants (Fig 7). Model B, which had an excessively high occlusal force overloading of the superstructure for 1 week, demonstrated lack of integration with the bone in small areas covering about two thirds of the buccal and coronal side and one fourth of the lingual and apex side (Fig 8). The quantity of bone resorption for model B was 1.90 mm at the lingual and 1.20 mm at the buccal. This approximated the resorption shown on the control. Model C was nearly the same as model B, except the overloading was for 2 weeks. Likewise, the quantity of bone resorption was again nearly that of the control (Fig 9). Model D was nearly the same as model B, except the overloading period was for 3 weeks. The implants were integrated with the bone, and there was little bone resorption at any surface (Fig 10). Model E closely resembled model B, except the overloading was for 4 weeks, the longest period of overload. Like the control model, model E showed good integration and the quantity of bone resorption was 1.66 mm at the lingual and 1.18 mm at the buccal. These values were almost the same as for the control (Fig 11).

Discussion

Occlusal trauma to natural human teeth can be divided into two categories: primary occlusal trauma without inflammation of peridontal tissue, and secondary occlusal trauma with inflammation.[19] Characteristic of primary occlusal trauma are bone defects and resorption without inflammatory changes in the periodontal tissue. Assuming that primary occlusal trauma to an implant takes place, several histologic differences can be identified between a natural human tooth and an implant, such as the presence of the periodontal membrane and the different attachment of peri-implant tissues.[20,21]

The periodontium is especially important for occlusion. Previous studies have demonstrated that the application of an excessive occlusal force to a natural tooth causes the periodontal ligament to react to

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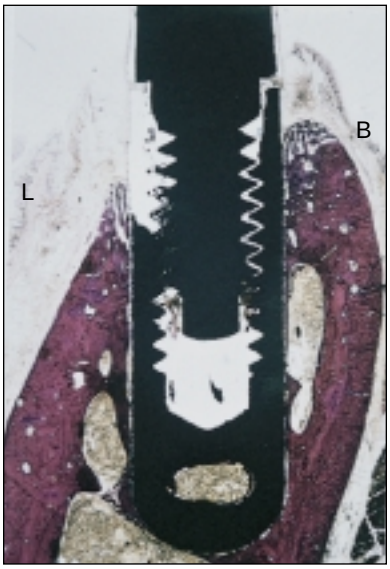
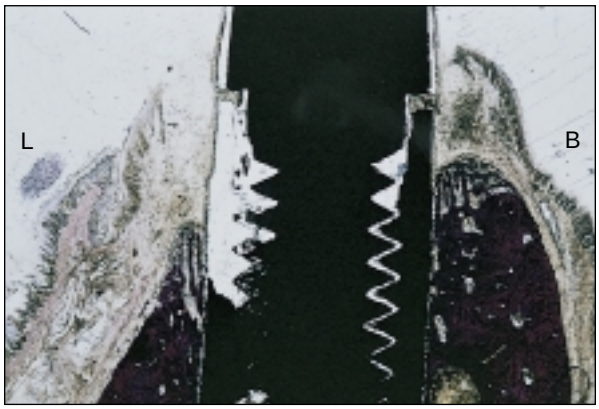
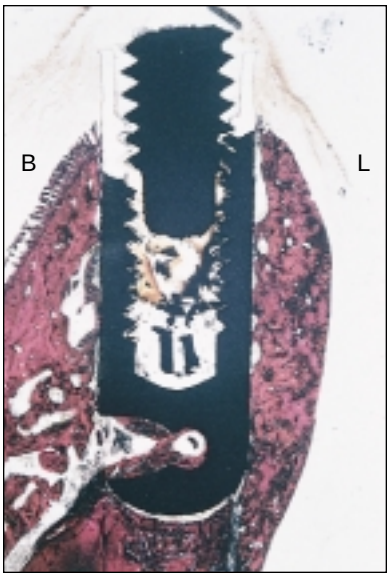
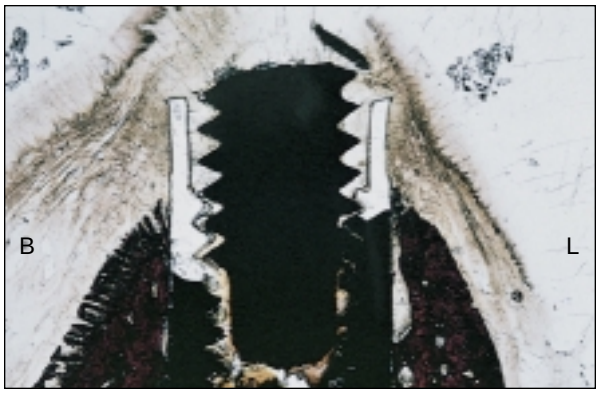




Figs 10a and 10b Model D (3 weeks occlusal-force overloading) demonstrated integration with the bone for both implants, and there was little bone resorption for any surface. Fig 10a: Original magnification × 10. Fig 10b: Original magnification × 30.





Figs 11a and 11b Model E (4 weeks occlusal-force overloading) was overloaded the longest of any subject. This model showed good integration, with bone all around the implants. The quantity of bone resorption was 1.66 mm at the lingual (L) and 1.18 mm at the buccal (B). These values were almost the same as for the control. Fig 11a: Original magnification × 10. Fig 11b: Original magnification × 30.

tooth movement from occlusal stress, compressing in the direction of the force, and stretching the membrane on the opposite side.[22] However, when occlusal stress is transient, the periodontal tissue recovers immediately, and no pathologic problem arises in most cases.[23] When an abnormal occlusal force lasts for an extended period, the periodontal bone surface undergoes resorption or formation. When the injury stress lasts for an extended period, the periodontal bone surface undergoes an increase in resorption and a decrease in bone formation.[24] This results in continuous bone resorption by the periodontal ligament, which leads to irreversible disease.

In the case of an implant, because the implant surface directly contacts the bone, it is suggested that bone-inducing factors may react to occlusal stress through the functional bony interface.[25] Studies of occlusal overload to an implant have recently demonstrated loss of marginal bone or complete loss of osseointegration.[10–12] Isidor[14] showed that of six implants with occlusal overload, two lost osseointegration completely, two others were osseointegrated in the apical part only, while the remaining two were still osseointegrated. However, these studies were not controlled as to the extent of excessive occlusal stress. Occlusal stress control is important to demonstrate

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the specific reactions of peri-implant tissue in response to the occlusal stress.

This study was based on the assumption that an implant integrates with bone in a histologically good condition. Histologic examination of the control showed that all implants without an experimental occlusal force appeared to have substantial bone-implant contact. Furthermore, the specimens with a superstructure that was occlusally excessive by about 100 μm for 1 to 4 weeks showed no obvious traumatic bone defects or resorption, although the implants had not completely integrated with the bone in the 1-week specimen. The experiment did not produce untoward effects possibly because of the following two reasons: *(1)* the height of about 100 μm may be within the physiologic tolerance limits, thus avoiding bone defects around an implant, and *(2)* the implant may be maintained by essentially cortical bone, and may more effectively absorb occlusal pressure. This indicates that long-term occlusal stress may stimulate blood circulation, which is an intraosseous bone-inducing factor that promotes bone metabolism, and consequently enhances bone remodeling to obtain the width needed to counter occlusal stress.[26]

Summary

This qualitative experimental system could not determine the limits of superstructure height needed to induce remodeling phenomena. It was impossible to determine the effect of traumatic occlusion as a factor in producing bone formation or resorption. What this study has demonstrated is that all occlusal stresses do not necessarily lead to bone resorption.

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