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SCIENTIFIC SECTION

The effects of a static magnetic field on orthodontic tooth movement

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Introduction

Orthodontic tooth movement, which requires formation and resorption of alveolar bone may be influenced by a magnetic field. The promotional effects of pulsed electromagnetic fields (PEMF) on bone metabolism have been well-demonstrated, i.e. enhancement of osteoblastic proliferation[1] and differentiation,[2] effects on alkaline phosphatase production,[3] and net flux and uptake of calcium.[4] PEMFs have been successfully used in the treatment of bone fractures, bone grafts, osteotomies, osteonecrosis, and osteoporosis.[5,6] As for the effects of PEMF on tooth movement, it has been suggested that PEMF could increase bone deposition and the rate of tooth movement.[7,8] Although PEMFs yield both a magnetic field and electric current, no definite conclusion can be drawn as to which factor is more responsible for bone formation.

Rare-earth magnets, which generate a static magnetic field (SMF), have also been used for many years as a 'force source' in orthodontic treatment such as space closure,[9] molar distalization,[10–12] intrusion,[13] and traction of impacted teeth,[14–16] and palatal expansion.[17] Effective tooth movement may be induced by an attractive magnetic force which increases as the distance between the magnets decreases.[18] Some studies have suggested that SMF may:

- increase the rate of bone repair at osteotomy sites;[5]
- increase new bone deposition and the amount of orthodontic tooth movement;[8]
- stimulate bone formation and regulate its orientation;[19]
- prevent decreases in bone mineral density caused by surgical invasion or implantation.[20]

However, controversy remains as to whether or not the biological effects of SMF contribute to tooth movement. To date, there have been no studies examining whether whole-body exposure to SMF influences tooth movement instead of using fine magnets incorporated into orthodontic appliances.

Accordingly, the purpose of this study was to determine whether the application of SMF could influence the pattern of tooth movement and changes to periodontal tissue during experimental orthodontic tooth movement in rats.

Materials and methods

Animals

Thirty-four , six-week-old male Wistar rats were used in this study. All animals were purchased from Japan SLC, Inc., for reasons of availability, cost and genetic homogeneity. This also provided an advantage for comparison with other work. Rats were numbered 1 to 34; animals numbered with an odd number served as the controls. The rats were randomly divided into two groups: control and experimental (17 animals in each group). Fifteen animals in each group served for measurements of tooth displacement, and two animals in each group served for the histological examination. A sample size calculation for the number of animals necessary to achieve 80% power and a significance level of $P<0.05$ was carried out using a two-sided continuity corrected chi-squared test.[21] A sample size of 15 animals per group was calculated as sufficient to detect a difference in tooth displacement of 0.10 mm between two groups.[22–24] The rats were fed a diet of pellets with water *ad libitum*. The animals in the experimental group were exposed to a static magnetic field during the experimental period. To assess whole body effects, body weight was recorded prior to each procedure. Ethical clearance was granted by the animal experiments' ethics committee of Kyushu University. All rats remained healthy throughout the experimental period, and no rats died or lost body weight.

Static magnetic field – exposure system

In the present study, SMF was applied using the experimental magnetic unit (X-5046, NEOMAX Co.,

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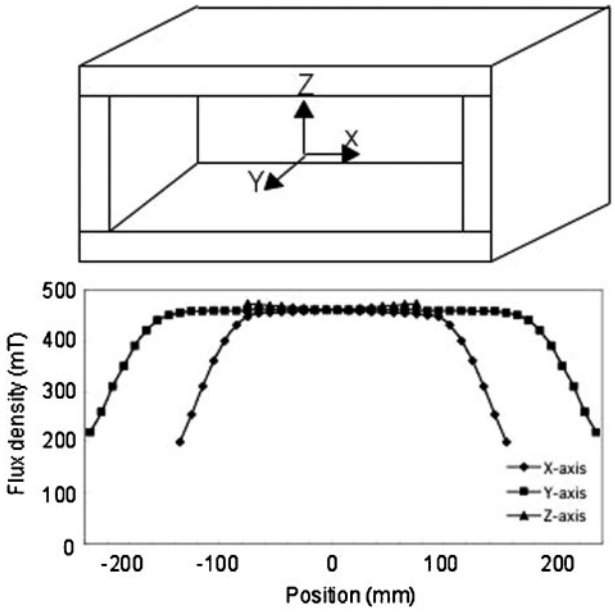

Figure 1 Distribution of magnetic flux density inside the unit. The minimum density was 200 mT, while the maximum density was 460 mT at the central area

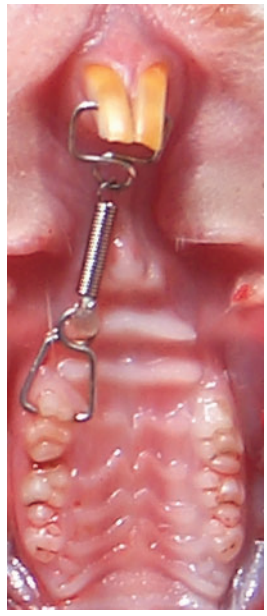

Figure 2 Orthodontic appliance used in the experiment

Osaka, Japan). SMFs were produced by built-in Neodymium-iron-boron magnets (NEOMAX47, NEOMAX Co., Osaka, Japan) at the top and bottom of the unit. The magnetic flux density was monitored with a Gauss/Tesla meter (SERIES 6010, F.W.BELL, Orlando, FL, USA). The distribution of magnetic flux density inside the unit is shown in Figure 1. The flux density in the central area was 460 mT. The rats in the experimental group were kept in an acrylic cage placed in the unit during the experimental period.

Induction of tooth movement

An orthodontic appliance was inserted on the right maxillary first molar and a mesially directed force of 40 g was applied (Figure 2). The force level was verified using a dynamometer. To prevent slippage of the appliance, notches were made on the lateral sides of the incisors and molar. A stretched stainless steel closed-coil spring (0.006×0.020 inch, 3MUnitek, USA) was suspended between the maxillary right first molar and two maxillary central incisors. Insertion of the orthodontic appliance was performed under general anaesthesia via intraperitoneal injection of sodium pentobarbital (40 mg/kg; Abbot Laboratories, IL, USA) following the administration of inhalant anaesthesia with diethyl ether.

Measurement of tooth displacement

On days 0, 1, 3, 5, 7 and 14 of tooth movement, silicone impressions (STANDOUT, Kerr, MI, USA) of the right maxillary molars were taken under anaesthesia with inhaled diethyl ether, and models were cast with dental stone (New Plastone, GC Co. Ltd, Tokyo, Japan). The relative separation between the first and second molar was measured using digital calipers (DIGIMATIC, Mitutoyo, Kanagawa, Japan) with sharpened tips (accurate to 0.01 mm) in order to ascertain the distance between the distobuccal cusps of these molars. Measurements of tooth displacement at each time were repeated 5 times for each animal and the mean value was taken as the tooth displacement (mm). The rates of tooth displacement per day (mm/day) were worked out from the distance of tooth displacement. The same investigator carried out all the measurements blinded. The margins were calculated for intra-investigator reproducibility. They were compared by analysis of variance (ANOVA) followed by Scheffe's *post-hoc* test. No significant differences were found among the five measurements ($P>0.05$). A CONSORT diagram showing the flow of animals through each stage of the study is shown in Figure 3.

Statistical analysis

The group means and standard deviations were calculated for body weight, the amount of tooth displacement and the rate of tooth displacement. The statistical process was performed using Stat View version 5.0 (SAS Institute Inc., Cary, NC, USA). These data were compared between groups by analysis of variance (ANOVA) followed by Scheffe's *post-hoc* test. A level

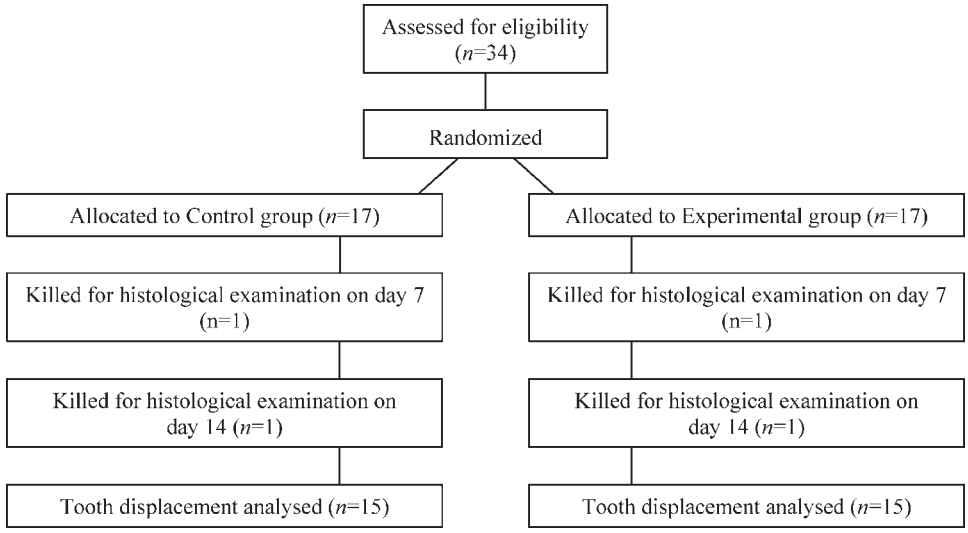

Figure 3 A CONSORT diagram showing the progress of the study

of $P<0.05$ was considered to indicate a significant difference.

Histological examination

Two animals in each group were killed on days 7 and 14 of tooth movement for the histological examination. Under general anesthesia the animals were perfused at a constant pressure via the left ventricle with 0.1M phosphate-buffered saline (PBS), followed by perfusion fixation with 8% paraformaldehyde in PBS. The maxillae were excised and immersed in the same fixative solution as that used for perfusion at 4°C overnight, and then decalcified in 10% ethylenediamine tetraacetic acid solution at 4°C for 12 days. Samples were cut in half along the sagittal plane, and embedded with pre-cooled O. C. T. compound (FineTek, SAKURA Co. Ltd, Tokyo, Japan) using conventional methods. Five-micrometer thick serial sections of the roots of the first and second molar were sectioned (in cross-section) with the surrounding tissues with a microtome. The mesial sides of the distobuccal root at the coronal one-third of the maxillary first molars were selected for observation. They were stained with haematoxylin and eosin.

Results

Weight changes of animals

The average weight of the rats increased continuously in both the experimental and the control groups. No significant difference in weight was found between the two groups (Figure 4). Food and water consumption appeared to be unaffected by the orthodontic appliance or exposure to SMF.

Tooth displacement

Orthodontic tooth movement was evidenced by a gradual increase in the inter-dental space between the first and second molars. No space was observed inter-dentally between the second and the third molars, thus indicating little or no mesial movement of the second molar. The cumulative tooth displacement gradually increased through 14 days in both the experimental group and the control group (Figure 5). At day 1 and day 3, there were no significant differences in tooth displacement between the two groups. In the following periods, the displacement in the experimental group was significantly greater than that in the control group at days 5, 7 and 14 ($P<0.05$).

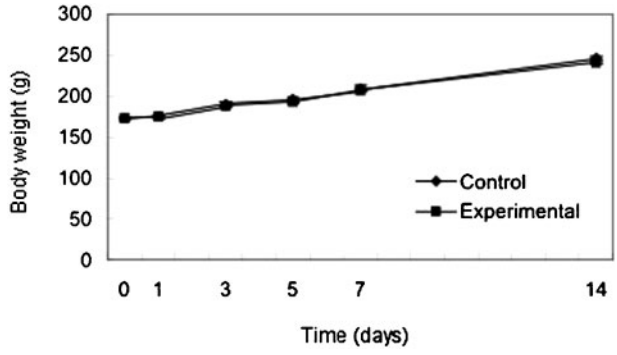

Figure 4 Body weight (mean ± SE). Changes in body weight. The weights of the rats increased continuously in both groups with no significant difference in weight between the two groups

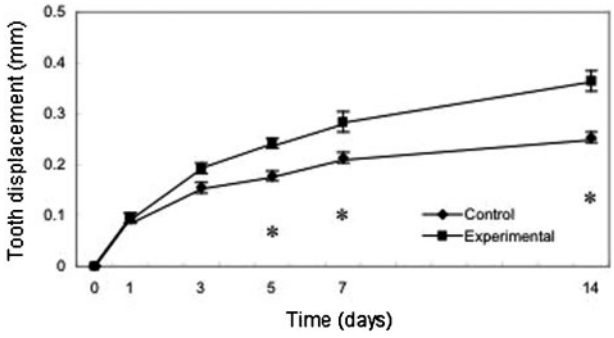

Figure 5 Cumulative tooth displacement (mean ± SE). The tooth movement gradually increased throughout the 14 days. At days 1 and 3, there were no significant differences in tooth displacement between the two groups. In the subsequent period, the displacement in the experimental group was significantly greater than that in the control group (*$P<0.05$)

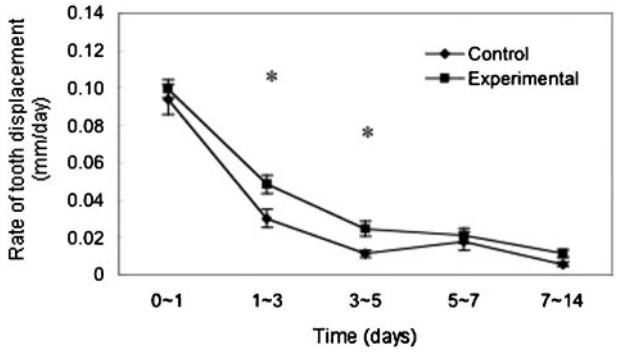

Figure 6 Rate of tooth displacement (mean ± SE). The rate of displacement from day 1 to day 5 in the experimental group was greater than that in the control group (*$P<0.05$)

Rate of tooth displacement

Changes in the rate of tooth movement are shown in Figure 6. An initial rapid movement caused by compression of the periodontal ligament was seen in both groups. The rate of tooth displacement from day 1 to day 5 in the experimental group was greater than that in the control group ($P<0.05$).

Changes to the periodontium

At day 7 in the control group, a limited area of hyalinization and bone resorption were evident (Figure 7a). At day 14 in the control group, an area of hyalinization and root resorption in the cementum were observed in some regions (Figure 7b). At days 7 and 14 in the experimental group, neither hyalinized tissue nor severe root resorption was seen (Figure 7c,d).

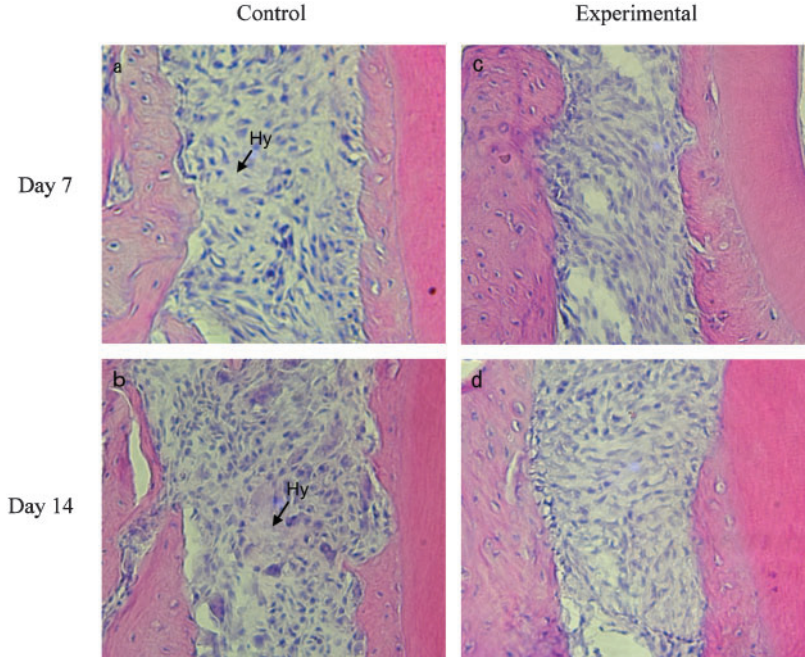

Figure 7 Mesial side of the distobuccal root in the right maxillary first molar (H&E stain). (a) At day 7 in the control group, a limited area of hyalinization (Hy) and bone resorption were evident. (b) At day 14 in the control group, a hyalinized area and root resorption in the cementum were observed in some regions. (c,d) At days 7 and 14 in the experimental group, neither hyalinized tissue nor severe root resorption was seen

Discussion

In each group, tooth displacement was on average 0.1 mm at day 1. Several authors have reported a periodontal ligament (PDL) of 0.1 mm in width in normally occluded rats.[25,26] Therefore tooth displacement of 0.1 mm at day 1 could perhaps be explained by the visco-elastic modification of the PDL and the strain on the alveolar bone. Tooth displacement gradually increased throughout the 14 days. Although there were no significant differences in cumulative tooth displacement between the two groups up until day 3, in the subsequent period, the displacement in the experimental group was significantly greater than that in the control group. The difference in cumulative tooth displacement from day 5 to day 14 between the two groups is considered to reflect the difference in the rate of tooth displacement from day 1 to day 5. The initial rapid tooth movement is attributed to compression of the PDL which is followed by formation of hyalinized tissue at subsequent experimental periods, indicated by cessation of tooth movement at the 'lag' phase. Recent reports have suggested that the application of PEMF in conjunction with orthodontic forces can increase the rate of orthodontic tooth movement of incisors in guinea pigs, accompanied by the absence of a 'lag' phase.[7,8] In the current investigation, the rate of tooth displacement decreased after the initial movement, although decrease in the rate of tooth displacement in the experimental group was smaller than that in the control group. Histological examination showed hyalinized tissue at days 7 and 14 in the control group, although no hyalinized tissue or root resorption in the cementum was observed in the experimental group. The suggestion that SMFs induce earlier formation and removal of hyalinized tissue[27] was supported in this study. This may represent either a suppression of clastic inflammatory activity or conversely, facilitated early repair of tissue. The suggestion that SMFs shorten the recruitment and initiation phase of osteoclast development[8] may explain why the modulatory effect of SMF appeared significant during the early period of tooth movement.

A weakness of the study was that the force applied to move the rat molar was heavy from the viewpoint of the histological change of periodontal tissue. It should be pointed out that an initial orthodontic force of 40 g could be converted into 160 g/cm^2 using the root area of the rat molar.[28] This is approximate to the force magnitude recommended by Jarabak[29] and has been applied in many studies dealing with experimental tooth movements in rats.[30,31] On the other hand, some studies have demonstrated that light continuous forces produce effective tooth movement with minimum tissue damage such as hyalinized or necrotic change in periodontal tissue and root resorption.[32,33] Kohno *et al.* have reported that tooth movement under light forces (less than 10 g) was constant and did not show a 'lag' phase seen under heavy forces.[34] Further studies on the effects of SMF using light orthodontic force are required.

There are some strengths associated with this study. For example, we adopted whole-body exposure to SMF in order to exclude the influence of attraction or repulsion or corrosion of the magnet. Many researchers have investigated the effects of SMF on orthodontic tooth movement by using fine magnets incorporated into orthodontic appliances. Secondly, the magnetic unit we used in the current study produced SMF of at least 200 mT at the area farthest from the center of the unit, which was considered sufficient to induce tissue reaction. In many studies of magnetic fields, the flux density was up to 100 mT. In the study using rat calvaria cell culture,[35] SMF of 160 mT stimulated bone formation by promoting osteoblastic differentiation and/or activation. Tengku *et al.* reported that incorporation of SMF of 10–17 mT into an orthodontic appliance did not enhance tooth movement, despite the increase in tartrate-resistant acid phosphatase activity.[27] The pattern of tooth movement and the changes to periodontal tissue under such strong SMF have not been discussed.

The results of this study indicate that incorporation of SMF into an orthodontic appliance may have the potential to produce effective tooth movement and shorten a treatment time.

However, further investigations into the long-term effects of SMF on tissue reaction are also necessary when the clinical application of SMF is considered.

Conclusion

In conclusion, the present findings suggest that the application of SMF can accelerate orthodontic tooth movement in rats. SMF was able to increase the rate of tooth movement during the early period of its application.

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