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A new idea and method of tooth movement using a ratchet bracket

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SUMMARY Since ideally effective tooth movement in orthodontics should occur without causing damage to the periodontal ligament (PDL), a new bracket with a ratchet-locking system, the 'Ratchet Bracket', was designed to produce tooth movement while maintaining blood circulation. To define the mechanism of the appliance, a histological study was carried out on four Beagle dogs (9 months old) and a clinical study on five female patients (11 years to 38 years 10 months of age).

Five upper canines in the dogs were moved 1.82 mm per month. On light microscopic observations, vascular forms showed a round–oval shape, without undermining bone resorption. No root resorption was observed in the compressed PDL at days 1, 14, and 35 of the experimental period. On fluorescent images at day 46, distinctive bone formation was apparent at the tension side.

In the clinical investigation, nine upper canines in the five female patients were moved 1.92 mm per month. A wide and long alveolar hard line was seen only on the tension side of the canines on dental radiographs, indicating bodily tooth movement, without obvious signs of root resorption in all subjects. Neither spontaneous pain nor pain during biting were reported.

The findings indicate that use of the ratchet bracket could result in rapid and pain-free tooth movement with vascular clarity to maintain blood circulation in the PDL.

Introduction

For effective tooth movement, it is generally accepted that a continuous force is required. An unavoidable consequence, however, is the appearance of degenerating tissue in the compressed periodontal ligament (PDL). It has been suggested that this is the result of obstruction of blood flow and mechanical damage following PDL compression (Reitan, 1960; Rygh, 1974; King and Fischlschweiger, 1982; Brudvik and Rygh, 1994; Nakamura *et al.*, 1996; Kurol and Owman-Moll, 1998; Noda *et al.*, 2000) as well as discomfort and pain (Oliver and Knapman, 1985; Kvam *et al.*, 1989; Brown and Moerenhout, 1991; Jones and Chan, 1992; Scheurer *et al.*, 1996).

The ultimate goal is thus to accomplish effective tooth movement without causing PDL degeneration. Kondo (1969) reported that blood circulation is maintained, providing compression remains within one-third of the PDL width. On the basis of that author's findings, a new bracket with a ratchet-locking system was designed. This 'ratchet bracket' can be used to move teeth over short distances, i.e. within the width of the PDL, maintaining blood circulation.

In the present study, the histological, clinical, and radiographic outcome of the use of the ratchet bracket were assessed to determine if the system produces tooth movement without inducing damage to the periodontal tissue and pain or discomfort.

Materials and methods

Structure and mechanism of the ratchet bracket

The ratchet bracket (Figure 1a–f) incorporates a ratchet mechanism to permit small tooth movements within the width of the PDL. It consists of a bracket base, a bonding base, a tube with inside dimensions of 0.55 × 0.7 mm, a wire slot of 0.018 inches, a ratchet spring, tie wings, and a ratchet rod. The rod has a cross section of 0.52 × 0.7 mm and a length of 7 mm. The grooves are cut perpendicular to the long axis of the rod, approximately 0.2-mm deep and spaced at 0.26-mm intervals. In addition, 0.016 × 0.022-inch stainless steel rectangular wire is soldered to one end of the rod.

The operation of this appliance is as follows: the rod is placed into the tube and is secured in place by the ratchet locking into the grooves. Each individual ratchet action permits the rod to move in the tube by 0.26 mm, up to a maximum of 7 mm.

Histological study

The Institutional Animal Care and Use Committee of the Tsurumi University approved the animal protocols, and the experiment was carried out according to the Guidelines for Animal Experimentation of Tsurumi University.

In the present study, a ratchet bracket was used for distal movement of the upper canines in four 9-month-old male

Beagle dogs (Table 1). A modified lingual arch fixed to the upper third incisor and second and third molars was used as anchorage (Figure 2a,b). One dog was served as the control. The bracket base was soldered on the lingual arch near the first molar, and the rod was fitted as a sectional arch between the canine and the bracket. An e-loop was added into the arch to provide resilience for ratchet activation (Figure 2b). The ratchet rod was inserted into the tube on the bracket base to activate the bracket (Figure 2a,b). The interval for ratchet activation (Figure 3) was based on the following reports. The interval between the initial and second activations was 7 days as Kvam (1969) reported that the PDL width at the compression side expanded significantly 7 days after tooth movement, and Vandevska-Radunovic *et al.* (1994) who found that blood flow in the PDL increased significantly up to the seventh day after tooth movement. The second and later activations were at 4-day intervals as Hughes and King (1998) found that significant tooth movement occurred approximately 3 days after appliance reactivation.

The periods of tooth movement were on days 1, 14, and 35 in three dogs ($n = 2$ in each group) for vascular appearance and PDL width, and on day 46 in one dog ($n = 1$, right side) to determine bone remodelling on fluorescent observation. The fluorescent substances were tetracycline (30 mg/kg body weight, Wako Chemical Co., Osaka, Japan) and calcein (1.6 mg/kg body weight, Wako Chemical Co.). Tetracycline was administered intraperitoneally at day 7 before tooth movement, and on days 21 and 44 after tooth movement. At the end of the various experimental periods, the dogs were killed by perfusion of 10 per cent neutral formalin fixative through the ascending aorta under deep anaesthesia, and bone tissue, including the upper canines, were excised. Specimens at days 1, 14, and 35 were decalcified with K-CX decalcifying solution including 1.35 N HCl (Fujisawa Pharmaceutical Co. Ltd., Tokyo, Japan) for 6 weeks, and embedded in paraffin using a conventional procedure (Yamada, 1987). Sections 6–7 µm stained with toluidine blue were prepared for light microscopic observation. Fluorescent-prepared specimens were embedded in Rigolac polyester resin (Ouken Co. Ltd., Tokyo, Japan) without decalcification. Sections (75–85 µm thick) were made from the alveolar crest region of the canines, and were observed under a fluorescent microscope.

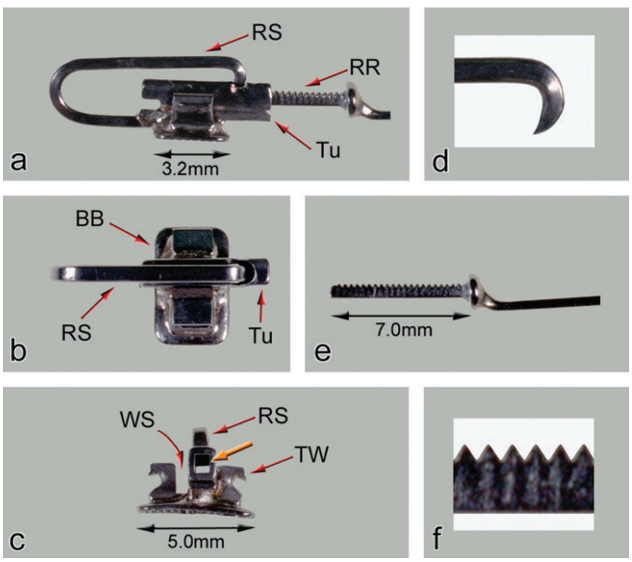

Figure 1 The ratchet bracket and its components. (a) Lateral view of the bracket. A ratchet rod (RR) is inserted into a tube (Tu) with internal dimensions of 0.55 × 0.7 mm, and locked by a ratchet spring (RS). (b) Upper view; a tube is soldered on a bonding base (BB). (c) Frontal view; the tip of the ratchet spring (yellow arrow) can be seen through the tube. WS: wire slot TW: tie wings. (d) A magnified image of the tip of the ratchet spring. (e) Lateral view of the ratchet rod. The rod has a cross section of 0.52 × 0.7 mm and is 7 mm in length. Stainless steel rectangular wire 0.016 × 0.022 inch is soldered to one end of the ratchet rod, in which the soldered region is utilized as fingernail stop to insert into the rod. (f) A magnified image of the ratchet rod. The grooves are approximately 0.2-mm deep and spaced at 0.26-mm intervals.

Table 1 Data showing the number of month old animals in the study together with the tooth moved, the experimental period, and the applied histological procedure.

Animal	Upper canine	Experimental tooth movement (days)	Histological procedure
1	Two (right/left)	0 control	
2		1	
3		14	
4		35	
5	One right	46	Fluorescent
	One left	0 (control)	staining

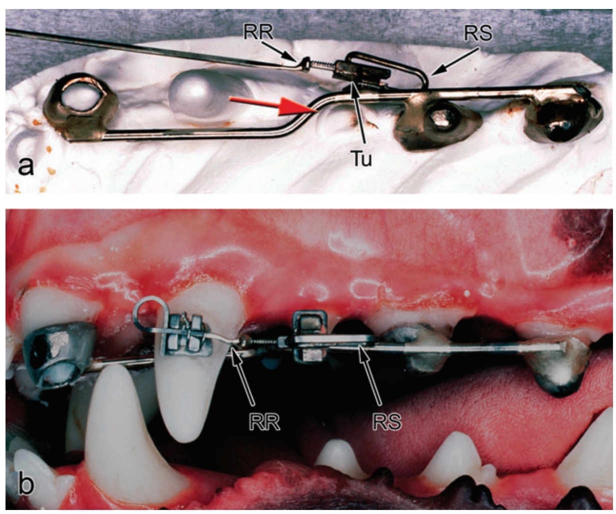

Figure 2 A modified lingual arch with a ratchet bracket. (a) Occlusal view of the appliance on a cast model before setting. Red arrow: direction of force. (b) Setting of the ratchet bracket for distal movement of an upper left canine of a Beagle dog. The appliance is fixed to the upper third incisor and the second and third molars are used as anchorage. RR: ratchet rod; RS: ratchet spring; and Tu: tube.

Clinical study

Use of the ratchet bracket was explained to five female patients, aged 11 years to 38 years 10 months. The bracket was used for distal movement of nine upper canines in the patients. The first premolars had been extracted, and the brackets were placed on the upper second premolars. The rod with an e-loop was fitted as a sectional arch between the canine and second premolar (Figure 4a). Another sectional arch, between the second premolar and second molar, and a lingual arch with a palatal rest were placed if required to increase intra-maxillary anchorage. The end of the rod-soldered archwire was bent on the mesial side of the canine bracket, and tied firmly. A fingernail was used to insert the ratchet rod into the tube in order to activate the bracket. The patients were able to operate the ratchet at home (Figure 4b). The interval for bracket activation was the same as for the Beagle dogs. The bracket was adjusted at 3- to 4-week intervals, and the total period of tooth movement ranged from 40 to 91 days.

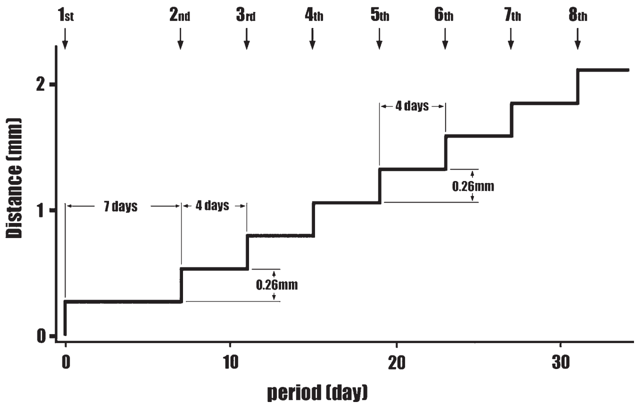

Figure 3 Timing of ratchet activation during tooth movement. The second activation was performed 7 days after initial activation. Thereafter, activation was at 4-day intervals.

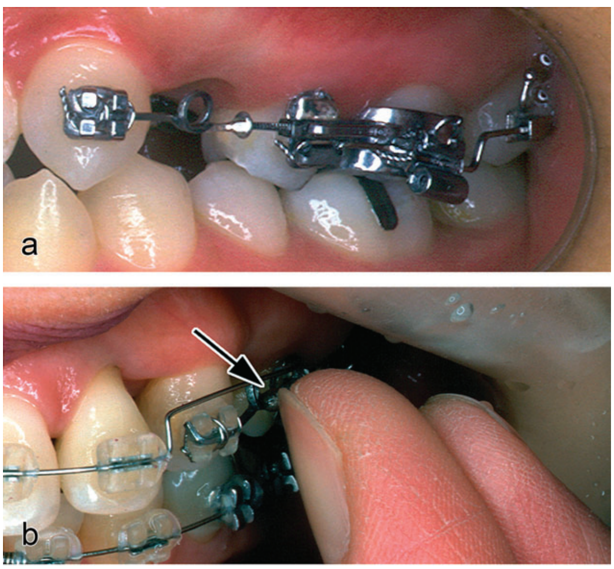

Figure 4 The setting and operation of the ratchet bracket. (a) A ratchet bracket is set on the upper the left second premolar, and a ratchet rod, as a sectional arch, is fixed to the left canine in order to move the tooth distally. An e-loop is used to provide resilience for ratchet activation. (b) Activation of the bracket. The ratchet rod is inserted into the tube using a thumbnail (arrow).

Assessment of the ratchet bracket

Pre- and post-treatment study casts were made to measure tooth movement between the upper third incisor and canine in the dogs and the upper canine and second premolar in the female patients. Samples from the dogs were measured on days 14 ($n = 2$), 35 ($n = 2$), and 46 ($n = 1$). Pre- and post-treatment dental radiographs were also obtained to assess root resorption and bone formation in the patients.

In addition, during treatment the patients were asked to record their experiences concerning spontaneous pain and pain during biting. If pain was reported, this was classified into four levels: none, light, middle, or strong.

Results

Using the ratchet bracket, the upper canines in the Beagle dogs were moved distally with slight tipping. The canines were moved 0.24 mm [standard deviation (SD): 0.04] for 4 days, 1.82 mm (SD: 0.32) per month on average, and 2.8 mm for 46 days. No obvious radiographic sign of root resorption was seen on the outline of the experimental canine roots (Figure 5a) in the dogs or in the control animal (Figure 5b).

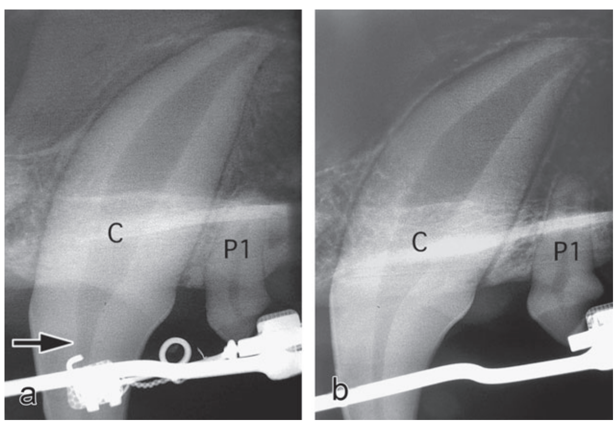

Figure 5 Dental radiographs of the upper left canine of a Beagle dog. (a) Forty-six days after start of distal movement of the canine (C) in experimental group. The arrow shows the direction of tooth movement. The periodontal ligament space is narrow and regular, and without root resorption. P1: first anterior molar. (b) Control canine (C) without tooth movement. There is no difference between the control and experimental groups in the ligament space. P1: first anterior molar.

On light microscopic images, the PDL widths at both the tension and compression sides in the alveolar crest region of control dog's canine were even and relatively equal (Figure 6a,b). Blood vessels dispersing in these areas showed a round–oval shape, and the tubular structure was clearly seen. On day 1 after tooth movement (Figure 6c,d), the PDL width was decreased approximately one-half compared with the control (Figure 6b) at the compression side (Figure 6d). Blood vessels dispersing in this area were a round–oval shape with a clear tubular structure. The PDL width at the tension side (Figure 6c) was increased and widened approximately one and a half times that of the control (Figure 6a). PDL width and vascular appearance on day 14 (Figure 6e,f) were similar to those on day 1. Osteoclasts were rarely observed and vessels with a round–oval shape were seen in the compressed PDL (Figure 6f). New bone formation was seen on the tension side (Figure 6e, arrows), where relatively large blood vessels were apparent near or among the processes. On day 35 (Figure 6g,h), the PDL width at the compression side was narrow, as seen on days 1 and 14. Typical blood vessels and a small number of osteoclasts (Figure 6h) were observed on the bone surface, indicating direct bone resorption. The PDL width at the tension side in this group was approximately two-thirds that of the control. Many small spaces, regarded as bone marrow, were seen at the tension side (Figure 6g), where the bone surface was uneven. No root resorption was seen in the experimental groups.

On fluorescent images of the control dog (Figure 7a–c) and the day 46 group (Figure 7d–f) at the alveolar crest region, new bone formation (indicated with fluorescent yellow by tetracycline and fluorescent green by calcein) was seen at the tension side of the experimental group. The newly formed bone had a brush-border-like structure (Figure 7d,f), and the PDL width was more than twice that of the control (Figure 7a,c), while the bone surface at the compression side of the experimental group was relatively smooth (Figure 7d,e) as also seen in the control (Figure 7a,b), where undermining bone resorption was not observed (Figure 7e). There was no visible difference between the tension and compression

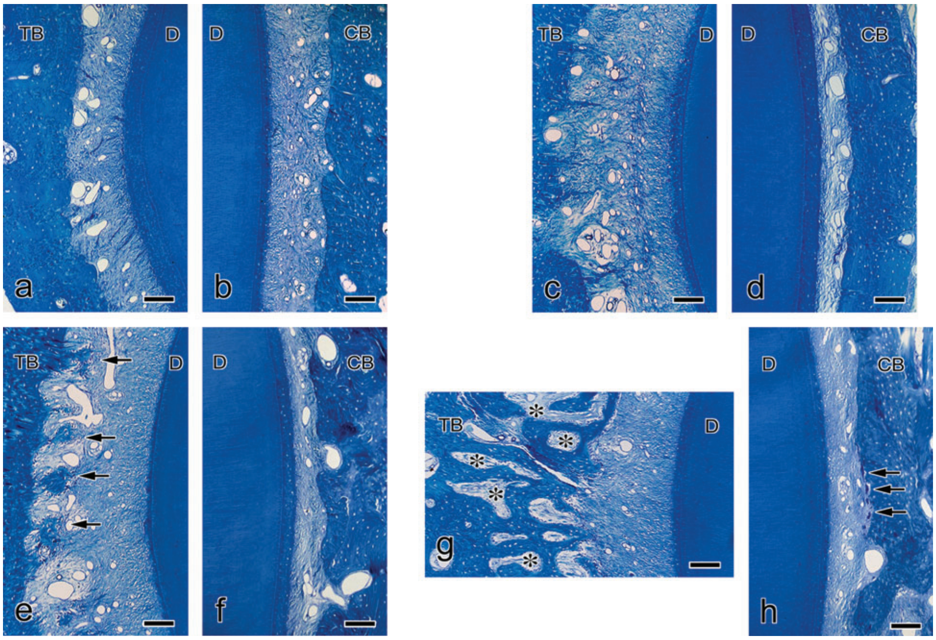

Figure 6 Light microscopic observations of the alveolar crest region of the upper canines in Beagle dogs. (a) Tension area. (b) Compression area of the control. The PDL widths of both sides are even and relatively equal. Blood vessels dispersing in this area show a round–oval shape with a clear tubular structure. TB: bone on the tension side; CB: bone on the compression side; and D: dentine. (c) Tension side at day 1. The PDL width increased approximately one and a half times that of the control, and many vessels are dispersing near the TB. (d) Compression side on day 1. The PDL width decreased approximately one-half that of the control. Blood vessels show a round–oval shape, and their tubular structure can be clearly observed. (e) Tension side on day 14. New bone formation can be seen (arrows), with relatively large blood vessels near the new bone. (f) Compression side on day 14. Osteoclasts are rarely seen, and the PDL width and vascular appearance are similar to those of day 1. (g) Tension side on day 35. The PDL width is approximately two-thirds that of the control. Many small spaces regarded as bone marrow (asterisks) are seen in TB, where the bone surface is uneven. (h) Compression side on day 35. The PDL width is narrow as seen on days 1 and 14. Typical blood vessels and a small number of osteoclasts (arrows) are apparent on the bone surface, suggesting direct bone resorption. No root resorption can be seen in this group or in the other experimental groups. All images ×14.5, bar = 300 μm.

sides in the control animal on the fluorescent images (Figure 7a–c).

Nine upper canines in the five female patients were moved distally (Figure 8a–f), approximately 0.26 mm (SD: 0.04) over a period of 4 days, 1.92 mm per month (SD: 0.28) on average, and 5.0 mm for 91 days in the longest period. All patients were able to operate the appliance correctly and with ease, by inserting the ratchet rod into the tube using their fingernail. A 'click' confirmed to the patient that the ratchet was functional. The patients reported neither spontaneous pain nor on pain biting during the period of tooth movement, although two patients felt slight pressure at initial activation. Slight tooth mobility was noted for a number of the canines during tooth movement, but this was less than that occasionally observed in canine retraction using elastic thread. Dental radiographs of the female patients (Figure 9a,b) showed a wide and long alveolar hard line only on the tension side of the

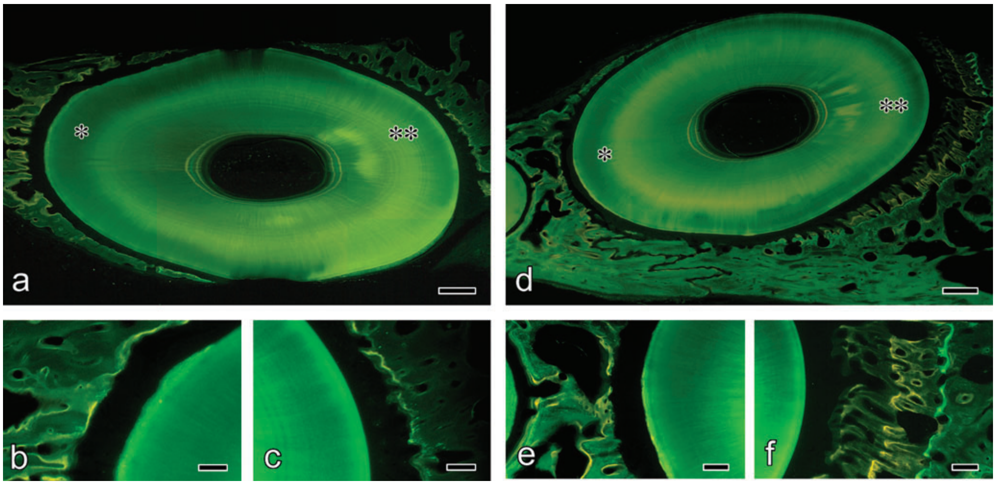

Figure 7 Fluorescent observations of the upper canines of a Beagle dog at day 46. (a) A low-magnified transversal section of the crest region in the right canine as a control. *distal (compression) side and **mesial (tension) side; ×5.3, bar = 1 mm. (b) A highly magnified image of (*) in (a); ×13.6, bar = 300 μm. (c) A highly magnified image of (**) in (a); ×13.6, bar = 300 μm. (d) A low-magnified transversal section of the crest region of the left canine of the day 46 group. *distal (compression) side and **mesial (tension) side; ×5, bar = 1 mm. (e) A highly magnified image of (*) in (d). The bone surface is relatively smooth, without undermining bone resorption; ×12.4, bar = 300 μm. (f) A highly magnified image of (**) in (d). Distinctive bone formation is shown as fluorescent yellow by tetracycline or fluorescent green by calcein. The newly formed bone is seen as a brush-border-like structure, and the width is over twice that the control PDL width; ×12.4, bar = 300 μm.

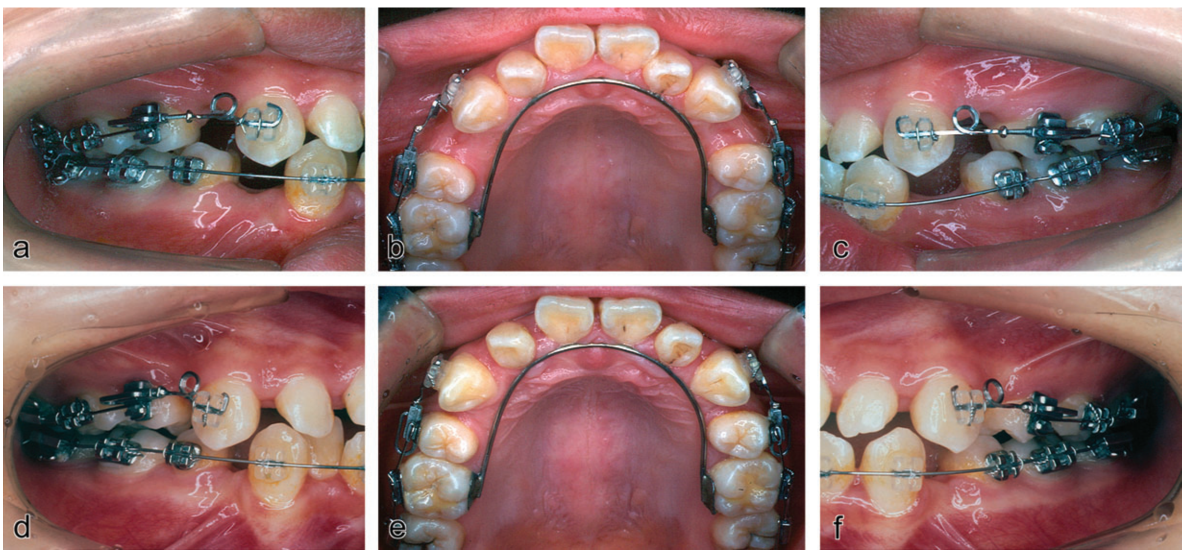

Figure 8 Photographs showing distal movement of the upper canines using the ratchet bracket in a 14-year-old female after 42 days. (a–c) Start and (d–f) end of the canine movement. The distances moved are 2.7 mm on the right and 2.9 mm on the left.

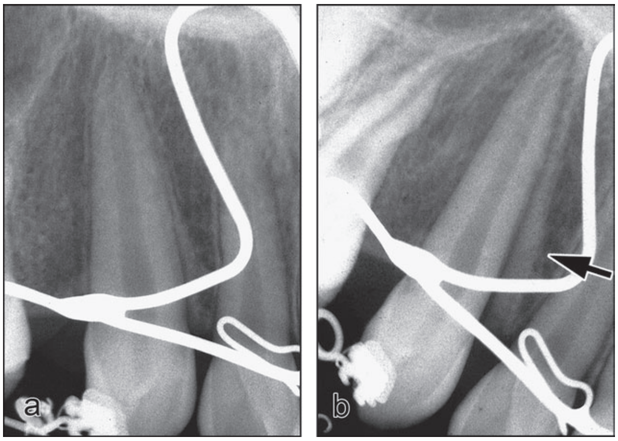

Figure 9 Dental radiographs of the upper right canine of a 13-year 3-month-old female patient. (a) Start of distal movement. (b) Forty-four days after tooth movement. A wide and long alveolar hard line is seen only in the tension side of the canines (arrow), indicating a phase of bodily tooth movement. No obvious sign of root resorption is seen on the outline of the root.

canines (Figure 9b), indicating a phase of bodily tooth movement. There were no obvious sign of root resorption in any of the subjects.

Discussion

Reitan (1957, 1960) reported that tooth movement using a wire-spring appliance induces two different phases, a hyalinization and a bone resorption phase. During the primary phase, compression of the periodontal tissues results in necrosis (Rygh, 1974; Brudvik and Rygh, 1994; Nakamura *et al.*, 1996; Noda *et al.*, 1997, 2000; Kurol and Owman-Moll, 1998) with temporarily slowed tooth movement (Reitan, 1957, 1960; King and Fischlschweiger, 1982; Noda *et al.*, 2000). Moreover, there is associated patient discomfort and pain as described in the Introduction; these detrimental effects of a treatment system that employs a continuous force have generally been accepted. Previous research has indicated that obstruction of blood flow damages the PDL and results in necrosis (Gianelly, 1969; Kondo, 1969; Khouw and Goldhaber, 1970; Rygh, 1972). Consequently, Burnstone (1985) suggested that smooth and 'non-pathological' tooth movement ought to occur as the result of application of an optimal force, with no generation of necrotic tissue during tooth movement. The ratchet bracket was designed to achieve this. By activating the ratchet, teeth can be moved a short distance (0.26 mm). The ratchet can then be reactivated for further movement, thus resulting in a controlled, interrupted, force. Maximal PDL compression occurs near the alveolar crest region on tipping movement (Reitan, 1957, 1960; Kvam, 1969; Storey, 1973; Satoh *et al.*, 1996; Noda *et al.*, 2000), and the width of the region in the upper canine of the present dog is approximately 500 µm. Kondo (1969) reported that blood circulation is maintained over one-third of the PDL width. When a shift of anchorage within the PDL width and distortion of the sectional arch occur at an initial activation of 0.26 mm, it may be possible to maintain the blood circulation in compressed PDL on tipping tooth movement. This possibility is supported by the results on day 1.

Furstman and Bernik (1972) reported that pain during tooth movement may depend on a combination of pressure, ischaema, inflammation, and oedema. However, the relationship between PDL damage and pain has not been clarified. PDL has a rich nerve network (Freeman, 1980), and it is considered that these symptoms arise from PDL compression, causing tissue degeneration or necrosis. The patients did not report pain during tooth movement, so the mechanism of the ratchet bracket may provide an improvement in biological tooth movement, with less damage at the maximally compressed PDL region.

The rate of upper canine retraction in humans shows tremendous variation, from 0.41 to 2.68 mm per month (Ziegler and Ingervall, 1989; Dinçer and Işcan, 1994; Sonis, 1994; Lotzof *et al.*, 1996; Darendeliler *et al.*, 1997; Iwasaki *et al.*, 2000), and this is likely to be dependent on force magnitude (Ziegler and Ingervall, 1989; Iwasaki *et al.*, 2000), force elasticity (Ziegler and Ingervall, 1989; Sonis, 1994), rate of tipping movement (Ziegler and Ingervall, 1989; Dinçer and Işcan, 1994), friction related to bracket and archwire (Ziegler and Ingervall, 1989; Lotzof *et al.*, 1996), and the patient's age (Darendeliler *et al.*, 1997). Thus, optimal force is subject dependent. The results of the present study demonstrate that the ratchet bracket can move canines by a controlled distance, 0.26 mm per ratchet activation, in Beagle dogs as well as in humans. The ratchet bracket causes tooth movement over a very short distance, i.e. within the PDL width, which does not depend on force magnitude, elasticity and friction of the bracket wire, or surface area. In short, the ratchet bracket provides a high level of control for tooth movement.

Radiographic assessment revealed a wide and long alveolar hard line on the tension side of the canine in the female patients. Additionally, fine bone formation was seen in the tension area of the dog canine on fluorescent observation. These results show active bone formation, and it is proposed that the force employed using the current system promotes new bone formation as observed in Figure 7f. On the other hand, a phase of undermining bone resorption could not be seen in the compression area of all experimental groups. This may indicate that the pressure of the ratchet activation of 0.26 mm is not sufficient to cause excessive bone resorption. It was presumed that the relatively smooth bone surface of this area reflects physiological bone remodelling, but more histological evidence concerning PDL cells including osteoclasts will be needed.

Root resorption was not observed histologically or on the radiographs of the female patients. However, the reasons for this cannot be explained from the present results. A possibility is that mechanics using an interrupted force can move teeth physiologically within the PDL.

Conclusions

The results of the current study support the use of the ratchet bracket for rapid and pain-free tooth movement. Using this system, biological evidence of mechanical damage was not apparent. Future histological assessment will be needed to provide further support for the use of the ratchet bracket for all teeth and its resultant force system.

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