Tooth movements in foxhounds after one or two alveolar corticotomies

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SUMMARY The aim of this split-mouth experimental study was to determine (1) whether corticotomy procedures increase tooth movement and (2) the effects of a second corticotomy procedure after 4 weeks on the rate of tooth movement.

The mandibular third and maxillary second premolars of five skeletally mature male foxhounds, approximately 2 years of age, were extracted. One randomly selected mandibular quadrant had buccal and lingual flaps and corticotomies performed around the second premolar; the other quadrant served as the control. Both maxillary quadrants had initial buccal flaps and corticotomies; one randomly selected quadrant had a second buccal flap surgery and corticotomy after 28 days. Coil springs (200 g force), along with a 0.045 mm diameter tube on a 0.040 mm diameter guiding wire, were used to move the mandibular second and maxillary third premolars. Records, including digital calliper measurements and radiographs, were taken on days 0, 10, 14, 28, 42, and 56. Multilevel statistical procedures were used to model longitudinal tooth movements.

The radiographic measurements initially showed increasing mandibular tooth movement rates, peaking between 22 and 25 days, and then decelerating. Total mandibular tooth movements were significantly (P < 0.05) greater on the experimental (2.4 mm) than on the control (1.3 mm) side. The rates of maxillary tooth movement slowed over time, with significantly (P < 0.05) more overall tooth movement on the side that had two (2.3 mm) than one (2.0 mm) corticotomy procedure.

Alveolar corticotomy significantly increases orthodontic tooth movement. Performing a second corticotomy procedure after 4 weeks maintained higher rates of tooth movement over a longer duration and produced greater overall tooth movement than performing just one initial corticotomy, but the difference was small.

Introduction

According to the American Association of Orthodontists (AAO), the length of comprehensive orthodontic treatment ranges between approximately 18–30 months, depending on treatment options and individual characteristics (AAO, 2007). To increase efficiency, orthodontists have tried various approaches to decrease treatment times. A method of orthodontic treatment using corticotomies has recently become popularized (Wilcko *et al.*, 2001), which uses bonehealing mechanisms in combination with orthodontic loads to decrease treatment times.

Corticotomy procedures are based on the regional acceleratory phenomenon (RAP) and normal bone-healing mechanisms (Frost, 1981, 1983). Under normal circumstances, any regional noxious stimulus of sufficient magnitude can evoke a RAP (Esterhai *et al.*, 1981; Frost, 1981). Accelerated RAP processes include perfusion, growth of bone and cartilage, accelerated turnover of bone, and bone modelling (Frost, 1983). Once evoked, regional soft and hard tissue processes accelerate above normal values. The main effects of RAP appear to be restricted to the region of the stimulus; even areas in close proximity

seem to be relatively unaffected by the RAP response (Bogoch *et al.*, 1993).

Previous experimental studies have shown that various stimuli, such as vitamin D, thyroxine, or electrical stimulus, can evoke a RAP in alveolar bone and increase tooth movements (High et al., 1981; High, 1987; Collins and Sinclair 1988). When RAP is initiated in alveolar bone, there is an initial burst of osteoclastic activity, which decreases bone density and eventually enhances osteoblastic activity (Ferguson et al., 2001). This is important because alveolar mineralization plays a role in tooth movement; the greater the mineralization of the alveolar bone the more difficult teeth are to move (Kole, 1959). It has also been established that osteoclastic activity is integral in tooth movement. Bisphosphonates, for example, decrease osteoclastic activity (Licata, 2005) and produce slower tooth movements (Igarashi et al., 1994). Therefore, any stimulus that increases bone turnover and decreases bone density might be expected to result in faster tooth movement.

Accelerated treatment times with corticotomies are based primarily on clinical case reports (Suya, 1991; Owen, 2001; Wicko *et al.*, 2001). Two studies have experimentally evaluated the effects of corticotomies on tooth movement. Iino et al. (2007) and Cho et al. (2007), who performed corticotomies and protracted the third premolars for 4 and 8 weeks, respectively, reported approximately twice as much tooth movement associated with corticotomies. However, only one of the studies (Cho et al., 2007) evaluated tooth movement beyond 4 weeks and this was limited to two beagle dogs. To minimize RAP effects associated with the extractions that were performed, both studies had healing periods ranging from 4-16 weeks. In terms of potential treatment efficiency, it is also important to understand the effects of corticotomies performed at the same time as extractions. These combined effects remain unknown. The effects of performing a second corticotomy on tooth movement have also not been investigated, although differential tooth movement might be expected.

The present study was designed so that the extraction of teeth and corticotomies were performed simultaneously in order to determine whether this novel approach may be clinically feasible. The null hypotheses of this study were:

- 1. Corticotomy procedures do not increase rates of tooth movements.
- 2. Performing a second corticotomy after 4 weeks produces the same amount of tooth movement as a single, initial, corticotomy.

Materials and methods

Sample population

The housing, care, and experimental protocol were in accordance with the guidelines set forth by the Institutional Animal Care and Use Committee. This study used five skeletally mature male foxhounds 2 years of age and weighing between 60 and 70 kg. The dog model was used because the size of the dentition approximates that of humans (Ren *et al.*, 2007) and studies have shown that tooth movements in dogs occur most efficiently when subjected to forces that approximate human clinical conditions (Pilon *et al.*, 1996; Daimaruya *et al.*, 2001; Cirelli *et al.*, 2003). All dogs were fed a soft diet for the duration of the experiment in order to prevent breakage of the appliances and to aid in healing after surgery.

Experimental design and group assignment (Figure 1)

All procedures were performed under general anaesthesia using ketamine (22 mg/kg/intramuscular; Bioniche Animal Health, Athens, Georgia, USA) and rompin (2.2 mg/kg/ intramuscular; Loyd, Shenandoah, Iowa, USA). Lidocaine (Novocol Pharmaceutical Inc., Cambridge, Ontario, Canada) 2 per cent (1/200K epinephrine) served as the local anaesthetic. Prior to surgery (day -21), maxillary and mandibular impressions of each dog's dentition were taken with heavy and light body polyvinylsiloxane material (Coltene Affinis;



Figure 1 Schematic representation of the maxillary and the mandibular corticotomies performed.

Coltene/Whaledent, Altstatten, Switzerland). Mesh-backed bonding bases were fabricated from the models for the mandibular second, fourth, and maxillary third premolars; bands were fabricated for the maxillary canines. Headgear tubes (0.045 mm diameter) were soldered to the bonding bases to maximize the diameter of the archwire (0.040 inch round stainless steel) with sliding mechanics, thus minimizing the chance of wire distortion.

Extractions (day 0)

The first surgery was performed on day 0. The third premolars in the mandibular quadrants and the second premolars in the maxillary quadrants were extracted. (They were hemisected, elevated, and delivered via forceps.)

Bone markers (day 0)

Bone markers (BM), made of 99.95 per cent tantalum, 1.5 mm long, and 0.5 mm in diameter, were placed in the mandible and maxilla (2 per quadrant) of each dog. They served as stable reference points for quantifying tooth movements. The distance between each set of BM was measured with callipers when they were placed.

Maxillary and mandibular corticotomy procedures (day 0)

One mandibular quadrant was randomly assigned to have corticotomy procedures (flap surgery and corticotomies) performed (Figure 2) at the buccal and lingual surfaces adjacent to the second premolar. The opposite side served as the untreated control, without flaps or corticotomies. A size 12 surgical blade (Hu-Friedy, Chicago, Illinois, USA) was used to cut and reflect full thickness buccal and lingual flaps just mesial and distal to the second mandibular premolar. A high-speed drill with a #702 tapering fissured bur (SS White Bur Inc., Lakewood, New Jersey, USA) was then used to make buccal and lingual cortical cuts (approximately 1—2 mm deep) around the premolar root, with copious saline irrigation. The flaps were closed with Goretex non-resorbable sutures, which were removed after 10 days.

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Figure 2 (A) Mandibular experimental side with buccal and lingual corticotomies. (B) Maxillary buccal corticotomy.

Using the same protocol as in the mandible, maxillary corticotomy procedures were performed around the third premolars in both quadrants but only on the buccal side. The anatomy on the palatal side of the foxhound maxilla did not allow for corticotomies. Following surgery, post-operative analgesic (Trophaject 0.2 mg/kg/intramuscular; Butler, Dublin, Ohio, USA) and antibiotics (Benzathine penicillin 300 IU/intramuscular three times/36hours; Butler) were administered.

The appliances were then bonded with Panavia F2.0 (Kuraray America, Inc., New York, New York, USA) according to manufacturers' instructions. Each quadrant had a constant force of 1.96 N (200 g) delivered by a 9 mm heavy Sentalloy® spring (GAC International, York, Pennsylvania, USA). In the mandible, the spring was attached to the second premolar with a 0.012 inch stainless steel ligature wire, then stretched and tied to the fourth premolar and molar. In the maxilla, the coil spring (also delivering 1.96 N) was attached with a 0.012 inch ligature wire from the canine to the third premolar.

Coil springs used for tooth movements were checked (*in situ*) and calibrated with a gram force gauge (Correx, Haag-Streit, Bern, Switzerland) every 2 weeks. After etching with 37 per cent phosphoric acid for 15 seconds, Transbond XT primer was applied, followed by Transbond XT composite (3M Unitek, Monrovia, California, USA), which was light cured with a 3M Unitek Ortholux® (3M, St Paul, Minnesota, USA) light emitting diode light for 20 seconds. Composite was bonded around the ligature wire to help keep it in place. The animals were fitted with Elizabethan hoods (Ejay International Inc., Glendora, California, USA) to prevent appliance damage.

Second surgery (day 28)

After 28 days, a second corticotomy procedure was undertaken in one randomly selected maxillary quadrant of each animal. Full thickness buccal flaps and cortical cuts were performed at the buccal surface of the third premolar, as previously described. The flaps were closed and sutured as previously described.

Records

The records included radiographs and calliper measurements. Records and force calibration were performed on day 0 (appliance delivery) and on days 10, 14, 28, 42, and 56. Periapical radiographs were used to evaluate tooth movement in each quadrant. Each radiograph was taken with the source angled at 45 degrees. To ensure standardization, an acrylic radiographic guide tray (Fastray®, Bosworth Co., Skokie, Illinois, USA) was fabricated. A film holder was fixed to the acrylic tray to attach a removable indicator arm and aiming ring (Dentsply, York, Pennsylvania, USA). Each animal had four radiographic trays, one for each quadrant, which were fitted to the canines and the first molars.

As an independent measure of tooth movement, intraoral measurements were taken with a digital calliper (Fowler ultra-cal II, Fred V. Fowler Co., Newton, Massachusetts, USA) by one operator (PAS) from the mesial of the second premolar buccal tube to the tip of the mandibular canine. Maxillary measurements were taken from the mesial of the third premolar tube to the canine tip. Each measurement was carried out three times and averaged.

Necropsy (day 56)

Prior to necropsy, the animals were anaesthetized with ketamine (22 mg/kg/intramuscular) and rompin (2.2 mg/kg/ intramuscular) and full final records were taken including radiographs, calliper measurements, and force magnitudes. The animals were then sacrificed using 1 cc of Beuthanasia-D (Schering-Plough Animal Health Corporation, Summit, New Jersey, USA).

Radiographic analyses

The radiographs were scanned (Epson perfection 4990, Long Beach, California, USA) and seven landmarks were digitized (Viewbox version 3.1.1.7, dHal, Athens, Greece) on each radiograph (Figure 3) by one operator (PAS) who was blinded as to experimental procedures performed.

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Figure 3 Radiographic landmarks and measurements including Cm, the most mesial point on the crown of the tooth; Cd, the most distal point on the crown of the tooth; Ct, the most superior/mesial point on the edge of bracket tube; BM1, the centre of the mesial bone marker; BM2, the centre of the distal bone marker; RP1, the superior intersection of the archwire and the distal of the bracket tube on second premolar; and RP2, the superior intersection of the archwire and the mesial of the bracket tube on the other banded tooth.



Figure 4 Average horizontal tooth movement (A) and velocities (B) of the mandibular second premolars on the control (no corticotomy) and experimental (buccal and lingual corticotomies) sides.

Following superimpositions on BM1 and BM2, the reference plane (RP1–RP2) digitized on the first (day 0) radiograph was transferred to the subsequent radiographs and used for orientation. Using BM1 as the origin, the horizontal and vertical distances of points Cm, Cd, and Ct from BM1 were measured. The angle Ct–Cm–BM1 was used to evaluate second premolar tipping. All measurements were made using the Viewbox software. To correct for

possible magnification differences between radiographs, the linear measurements were multiplied by the ratio of the actual inter-bone marker distance divided by the radiographic inter-bone marker distance.

Technical errors were assessed based on replicate analyses of 20 randomly chosen radiographs. Paired *t*-tests showed no significant (P > 0.05) systematic errors between replicates. Methods error $\left(\sqrt{\left(\frac{\sum d^2}{2n}\right)}\right)$ ranged from 0.09–

0.65 mm for the linear measurements and was 0.09 degrees for Ct–Cm–BM1.

Statistical analysis

Multilevel models were used to statistically determine treatment differences in the amount of tooth movement. The models were developed using the MLwiN (Centre for Multilevel Modelling, Institute of Education, London, UK) software and iterative generalized least squares estimating procedures (Goldstein, 1987).

The fixed portion of each model determined the polynomial that best fitted the repeated measurements of tooth movement as a function of time. The terms were tested statistically based on the standard errors; higher order terms were rejected sequentially until a lower order term attained significance (P < 0.05). The constant term described the tooth movement at day 56, the linear term the rate of change (velocity), the quadratic term acceleration, and the cubic term changes in acceleration. The random portion of each model partitioned variation between animals at the higher level and between measurement occasions (within animals) at the lower level.

Results

None of the dogs showed clinical signs of swelling or displayed healing problems of the periodontal tissues beyond 10 days post-surgery. Within 2 weeks of surgery, the tissues on the side with the corticotomy procedures appeared similar to the side without corticotomies. The radiographs showed no perceivable bone loss and there was no clinically evident recession of the tissues. After 10 days, none of the dogs displayed eating difficulties and there was no significant weight loss.

Statistical analysis showed no significant vertical movements of the teeth and no significant changes of Ct–Cm–BM1 angle.

The calliper measurements showed a significant difference in the total amount of horizontal tooth movement between the experimental and the control (averages of 2.5 versus 1.5 mm) sides of the mandible (Figure 4A). Mandibular tooth movement followed a cubic polynomial, with rates accelerating initially and then decelerating (Table 1; Figure 4B). The rates of tooth movement on the corticotomy side

Variables	Constant		Linear		Quadratic		Cubic	
	Estimates	SE	Estimates	SE	Estimates	SE	Estimates	SE
Control								
Radiographic	1.31	0.08	-1.17	3.64	-154.20	60.65	-552.336	267.77
Digital calliper	1.54	0.10	0.19	0.08	-0.10	0.04	-0.016	0.01
Experimental								
Radiographic	2.35	0.13	-4.29	5.74	-274.47	95.60	-884.90	422.03
Digital calliper	2.53	0.11	0.02	0.12	-0.27	0.06	0.04	0.01

Table 1Polynomial model describing mandibular second premolar movements (mm) in foxhound dogs subjected to a force of 200 g for56 days.

SE, standard error.

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increased until day 22 and then decreased. The control side showed increasing rates of movement until day 25. At peak velocity, the rate of tooth movement on the experimental side was 85 per cent faster than that on the control side. The rates of control and experimental tooth movement were similar at the end of the experimental period. Radiographically, there was approximately twice as much total mandibular tooth movement on the experimental than on the control side, averaging 2.4 and 1.3 mm respectively, over the 56 day experimental period.

In contrast to the mandible, the maxilla showed a simpler quadratic pattern of tooth movement, with rates of tooth movement decreasing regularly overtime (Table 2; Figure 5). Tooth movement on the two sides were similar through to day 36, after which the side with two corticotomies showed progressively more tooth movement than the side with one corticotomy. At 56 days, the calliper measurements showed no significant difference in tooth movement between the two sides. Radiographically, there was a significant difference in tooth movement between the side that received only an initial corticotomy (2.0 mm) and the side that received two corticotomies (2.3 mm).

Discussion

Orthodontic forces with the corticotomy procedures produced substantially greater mandibular tooth movements than orthodontic forces alone. Tooth movement based on the calliper measurements were consistently larger than those derived from the radiographic measurements, suggesting that the calliper points measured were not taken in the same plane of space. The relative differences between the control and the experimental sides support the findings of Iino *et al.* (2007) and Cho *et al.* (2007), who also found approximately twice as much tooth movement in beagle dogs. However, they reported greater absolute amounts of tooth movement, which could have been due to the animal model used. The foxhounds used in the present study have larger mandibles and thicker cortical bone than beagle dogs. Previous investigations that also used calliper measurements **Table 2** Polynomial model describing maxillary third premolarmovements (mm) in foxhound dogs subjected to a force of 200 gfor 56 days.

Variables	Constant		Linear		Quadratic	
	Estimates	SE	Estimates	SE	Estimates	SE
Control (one cortico	otomy)					
Radiographic	1.96	0.11	0.20	2.37	-97.329	16.58
Digital calliper	2.37	0.08	-0.06	0.11	0.19	0.05
Experimental (two	corticotomie	s)				
Radiographic	2.33	0.10	10.11	2.52	-45.12	17.60
Digital calliper	2.64	0.08	-0.53	0.02	NS	NS

SE, standard error.

NS, not significant (P > 0.05).



Figure 5 Average horizontal tooth movement of the maxillary third premolar on the side with one initial corticotomy and on the side with two corticotomies.

were not able to discount the possibility of tipping. The lack of change in Ct–Cm–BM1 angle suggests that the appliance system used in the present study was effective in minimizing tipping. The differences were probably not related to the forces used because little or no difference in tooth movement occurs between forces of 50, 100, or 200 g (Pilon *et al.*,

1996). The corticotomies may have produced greater tooth movements due to increased bone turnover (Collins and Sinclair, 1988; Verna *et al.*, 2000; Kale *et al.*, 2004).

Both sides of the mandible initially showed accelerating rates of tooth movement. The initial pattern of tooth movement on the control side differed from those previously described for the controls, which tended to slow down within a few days after initial tooth movement due to hyalinization and undermining resorption (von Bohl et al., 2004; Cho et al., 2007; Iino et al., 2007). While previous studies evaluating corticotomies waited from 1-6 months after extractions before initiating tooth movement, tooth movements were initiated immediately in the present study. This suggests that extraction of the third premolars caused a RAP on the control side, which has been shown to eliminate hyalinization of the periodontal ligament (Iino et al., 2007). RAP on the control side could have produced an accelerating pattern of tooth movement similar to but less than that on the experimental side. Alternatively, it is possible that the reduced mineralized bone that filled the extraction sites could explain the faster tooth movements observed at both the experimental and control sides.

Orthodontic tooth movements might also be expected to initiate a RAP. As shown experimentally by Deguchi *et al*, (2006), bone turnover rates are significantly greater on the side of mouth subjected to orthodontic forces than on the control side. Thus, both extractions and orthodontic tooth movements might be expected to have influenced the results of the present study, but these effects were controlled because both sides of the mouth were similarly treated.

The initial acceleratory phase was much greater on the corticotomy side than on the control side, with differences in tooth movement evident during the first 2 weeks. By day 10, the corticotomy side showed twice as much tooth movement compared with the control side. Iino *et al.* (2007) and Cho *et al.* (2007) also found approximately twice as much tooth movement after 1 week on the corticotomy side versus the control side. It has also been suggested that greater amounts of noxious stimulus produce a greater RAP effect (Frost, 1981, 1983), which might explain the difference in tooth movement between the experimental and the control sides.

In the mandible, the rates of tooth movement peaked at day 22 on the corticotomy side and at day 25 on the control side; peak velocity was 85 per cent greater on the corticotomy side. This finding is similar to previous studies that showed tooth velocities peak between the first (lino *et al.*, 2007) and third (Cho *et al.*, 2007) week after corticotomies were performed. Peak tooth velocities indicate a transition from the catabolic to the anabolic phase of RAP, when bone density is least and tooth movements might be expected to be greatest. After the peak, there was a deceleration of tooth movement in both the corticotomy and the control groups, with the rates on the corticotomy side approaching those on the control side at the end of the experiment. These findings support those of lino *et al.* (2007) and Cho *et al.* (2007),

who were not able to identify differences in rates of tooth movement between the corticotomy and the control sides at the end of their experimental periods. It has been shown that in rats, osteoid begins to mineralize after about 20–55 days (Ferguson *et al.*, 2001). According to those authors, anabolic modelling of alveolar trabecular bone adjacent to decortication increases 150 per cent by 3 weeks. Since the anabolic levels of RAP increase through time, it is reasonable to expect that tooth movement would slow as bone density increased, which possibly explains the decreased tooth movement seen during the last 2 week of the experiment.

At the end of the experiment (day 56), there was only marginally more tooth movement on the maxillary side that had two corticotomy procedures performed than on the side with one corticotomy. The side with only one corticotomy showed decreasing amounts of tooth movement during the last few weeks; the side with two corticotomies showed steadier rates of tooth movement throughout the experimental period. In other words, the second corticotomy maintained a higher rate of tooth movement for a longer period of time. However, the differences in tooth movement between one and two corticotomy procedures were small and seem insufficient to warrant a second surgical procedure for orthodontic patients. Considering the added expense and time involved, along with the potential health factors associated with periodontal surgery, a second corticotomy may not be warranted. Other methods of initiating the RAP, such as corticision (Young-Guk et al., 2006), laser (Youssef et al., 2008), or electrical stimulation (Takahashi et al., 1985) may provide a less invasive and a more cost-effective alternative, but all of these possibilities require further investigation. Based on the tooth movement rates in the mandible, a greater overall effect might have occurred if the second corticotomy had been performed at 6 weeks instead of 4 weeks because tooth movements on the side with one corticotomy would have had more time to slow down.

While corticotomies clearly increased the rates of tooth movement, significant reductions in treatment time of comprehensive cases remain questionable. Case reports have indicated that comprehensive orthodontic treatment can be completed in 4–9 months with corticotomies (Suya, 1991; Wilcko et al., 2000, 2001), whereas conventional orthodontics takes 18-30 months (AAO, 2007). Based on the present study and other longitudinal experimental evidence (Cho et al., 2007; Iino et al., 2007), tooth movement rates approach control values after approximately 3-7 weeks. As such, it is difficult to understand how treatment can be accelerated by 14-21 months with a single corticotomy. Even though dogs heal only slightly faster than humans (Frost et al., 1969), it is possible that there the RAP effect is different in humans than in dogs. The thicker cortical bone of dogs could also account for some of the differences. Since the greatest tooth movement during orthodontic treatment occurs during aligning and levelling of the dentition, which typically takes approximately 6 months (Franchi et al., 2006; Tagawa, 2006), corticotomies

might be best suited for this treatment phase. Importantly, controlled randomized trials are needed to ascertain the true efficacy and most appropriate time to perform corticotomies.

Contrary to expectations, there was greater tooth movement on the corticotomy side of the mandible than on the side of the maxilla that had only one corticotomy. Considering that mandibular cortical bone is thicker and more dense than maxillary bone (Miyawaki *et al.*, 2003; Deguchi *et al.*, 2006), less movement might have been expected. However, the second premolars were moved in the mandible, while the third premolars were moved in the maxilla and the size difference between these teeth could explain the observed differences in tooth movement. The differences may also have been due to the fact that the mandible had buccal and lingual corticotomies, while the maxilla had only a buccal corticotomy. This could have produced a greater RAP in one jaw than the other.

Case reports suggest little or no loss of gingival attachment associated with corticotomy (Kole, 1959; Suya, 1991; Wilcko *et al.*, 2001). The present study showed increased swelling and inflammation during the first 10 days following both the first and the second corticotomy. After 10–14 days, the tissues on the corticotomy side appeared similar to those on the control side. While no adverse effects have been noted, well controlled trials have not been performed to establish the health of the periodontal tissues after corticotomy. Histological data must also be evaluated to verify the mechanisms responsible for accelerating tooth movement. In order to more fully understand differences in tooth movement with and without corticotomies. It is also important to establish a clear association between the magnitude of injury and the duration and magnitude of RAP response in alveolar bone.

Conclusion

- Alveolar corticotomies and associated soft tissue surgery create conditions that significantly increase tooth velocities and tooth movements when orthodontic forces are applied.
- Performing a second corticotomy procedure after 4 weeks maintains the enhanced velocities of tooth movement for a longer duration. However, the differences in tooth movement do not appear to justify a second corticotomy.

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