Changes in Maxillary Canine Pulpal Blood Flow During Dentoalveolar Distraction Osteogenesis

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Objective: The aim of this study was to assess the effects of dentoalveolar distraction osteogenesis (DD) on the pulpal blood flow (PBF) of maxillary canines.

Materials and Methods: A laser Doppler flowmeter (LDF) was used to measure PBF in maxillary canines of 10 patients undergoing DD (study group) and 10 nonsurgical subjects who received no orthodontic treatment (control group). PBF was measured at baseline, at 4 and 7 days postoperatively, at the end of distraction and at the end of consolidation in the study group and at similar time-points in nonsurgical control subjects. Data were analyzed using paired and Student *t* tests, with the significance level set at 0.05.

Results: Study findings showed that baseline PBF values did not differ significantly between groups. PBF in the control group did not vary over time; however, in the study group, an initial decrease in PBF was observed at 4 days postoperatively and was followed by a gradual increase to preoperative levels at the end of distraction.

Conclusions: During the DD latency period, there appears to be a short-lived ischemic phase when perfusion of pulp tissue declines; however, blood-flow returns to normal by the end of distraction.

Key Words: Dentoalveolar distraction osteogenesis, laser Doppler flowmetry, pulpal blood flow, rapid canine retraction

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Moderate-to-severe skeletal problems are frequently treated with a combination of surgical and orthodontic therapy to accelerate orthodontic tooth movement or when tooth movement alone is unable to achieve a satisfactory outcome. A multitude of procedures including alveolar decortication, corticotomy, segmental alveolar osteotomy, distraction of the periodontal ligament, and dentoalveolar distraction osteogenesis may be selected to meet individual patient requirements. However, while these techniques shorten the duration of orthodontic treatment, most entail a range of risks to surrounding hard and soft tissue, including vascular[1] and neural[2] tissue damage that may be reflected in dental pulp.

Distraction osteogenesis (DO) is a gradual bone-lengthening technique that was first introduced by Codivilla[3] in 1905 and was popularized in the 1970s through Ilizarov's clinical and experimental orthopedic research.[4] DO has gained widespread recognition as an effective surgical method of lengthening bone, correcting deformities, and filling large bony defects. Although the distraction technique has been commonly used in the field of orthopedic surgery for more than 100 years, it was not until the early 1990s that distraction was used for the correction of craniofacial skeletal deformities. Since Guerrero et al[5] and McCarthy et al[6] first performed DO in human mandibles in 1990 and 1992, respectively, the procedure has been applied to various other bones of the craniofacial skeleton. In 1998, Liou and Huang[7] first investigated and applied the concept of distraction to orthodontic tooth movement by performing rapid canine retraction through distraction of the periodontal ligament (PD). In 2001, another technique for rapid canine retraction was developed using the concepts of DO.[8] As described and used by Iseri et al[8] and Kisnisci et al,[9] this technique, known as dentoalveolar distraction osteogenesis (DD), uses the dentoalveolus itself as a bone-transport segment for posterior movement, thereby eliminating the need for periodontal stretching and thus avoiding the excessive stress on periodontal tissue associated with Liou and Huang's[7] method of canine distraction.

Several studies have examined the time required for canine retraction as well as the amount of distraction, anchorage loss, and root resorption occurring with rapid canine retraction using surgical approaches.[7–10] Both PD and DD have been found to successfully achieve canine movement at a rate of more than 2 mm/wk with no loss of anchorage.[7–9] However, few studies have investigated the phenomenon of pulpal response to rapid canine retraction, and those that have report conflicting results. Kumar et al[11] found that a sample of 20 canine teeth that were vital before distraction all responded positively to electric pulp tests performed 6 months after the completion of distraction. Kharkar et al[10] reported similar results with a sample of 12 canine teeth. In contrast, Liou and Huang[7] reported only 5 of 15 distracted maxillary canines and 4 of 11 distracted mandibular canines reacted positively to electric pulp testing 1 month after distraction; however, the authors[7] stated that pulp vitality cannot be accurately determined by electric pulp testing, which can only evaluate pulp sensitivity. Indeed, it has recently come to be understood that true pulp vitality—that is pulpal blood flow (PBF)—cannot be evaluated using electric pulp tests, as both clinical and experimental studies have demonstrated that tooth-sensitivity tests cannot reliably measure vitality in teeth undergoing orthodontic treatment and/or maxillofacial surgery.[12,13] Laser Doppler flowmetry (LDF) may be a more reliable method for detecting blood flow in pulp tissue of teeth undergoing distraction. Considering that little is known about changes in PBF of canines after treated by distraction, this study used LDF to evaluate postoperative changes in PBF of maxillary canines following DD.

METHODS

Subjects and Surgical Procedures

This study was approved by the Institutional Review Board and Ethics Committee of the Ministry of Health's Kecioren Training and

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Research Hospital (Study no: B.10.4.ISM.4.06.68.49/586) and was conducted in compliance with the principles of the Helsinki Declaration. Informed consent was obtained from all participants. The sample consisted of 20 adult patients (age range, 18–25 years; mean age, 20.7 years) exhibiting Class II Division 1 malocclusion with increased overjet requiring therapeutic extraction of the maxillary first premolars followed by retraction of the maxillary canines. Intraoral periapical radiographs were taken, and patients with maxillary canine teeth with a history of trauma, root canal treatment, caries, restoration, previous orthodontic treatment, or excessive gingival display were excluded from the study. All participants were systemically healthy, with no evidence of hypertension or cardiovascular disease and no current usage of cardiovascular medication or nicotine. Study participants were randomly divided into a study group of patients treated with DD of both maxillary canines (n = 10 subjects and 20 teeth) and a control group (n = 10 subjects and 20 teeth) who received no surgical treatment, but which was included to account for temporal variability that may occur with repeated blood-flow measurements.[14]

Dentoalveolar distraction osteogenesis was performed on each patient in the study group using a procedure similar to Kharkar et al.[10] Under local anesthesia (Ultracaine DS Forte; Aventis Pharma, Zurich, Switzerland), a mucosal incision was made to expose the canine tooth, and multiple monocortical holes were made in the buccal bone medially and distally to the canine root using a round stainless-steel bur with copious saline irrigation. To minimize vascular compromise, holes were drilled 5 mm apically to the canine root apex[15] and connected using a thin, tapered stainless-steel bur. At this stage, the first premolar tooth was extracted, and large, round burs were used to carefully remove the section of buccal bone between the cuts in the distal canine region and the second premolar through the extraction socket. All bone apical to the extraction socket as well as any bony interferences in the buccal aspect between the canine and second premolar that might hamper the distraction process were eliminated or smoothed. Palatal cortical shelves and interdental bone were preserved. Fine osteotomes were inserted along the mesial aspect of the dento-alveolar segment to sever the surrounding spongy bone from its roots at the palatal cortex and neighboring teeth to ensure that the dentoalveolar transport segment included the buccal cortex and underlying spongy bone surrounding the canine root, while leaving the apical, lingual, and palatal cortical plates intact. The wound was irrigated with saline and closed in a single mucosal layer with an absorbable suture. Following osteotomy, a custom-made, stainless-steel, tooth-borne intraoral distraction device consisting of an anterior section, a posterior section, a screw, and a screw activator was placed as apically as possible to minimize tipping (Fig. 1A-C). After a 4-day latency period, the distraction device was activated once a day at a rate of 0.5 mm/day until the canine came into contact with the second premolar. Only minimal force was required to fully mobilize the transport segment. When distraction was complete, the device was left in place for a 4-week consolidation period, after which treatment continued with conventional fixed appliances. Patients were seen 3 times a week during the distraction process. The amount of distraction was calculated by measuring the distance between the canine and lateral incisor contact points preoperatively and at the end of retraction using a sliding caliper accurate to 0.1 mm (Yamayo digital calipers). The number of days required to complete retraction was also recorded for each tooth.

Laser Doppler Flowmeter

Pulpal blood flow was measured using an LDF (Periflux PF 4001, Perimed, Järfälla, Sweden), which records amounts of back-scattered light. The LDF output signal voltage is linearly related to red-blood-cell flow (number of cells × average velocity), which is recorded in perfusion units (PU) to provide a relative measurement of blood flow. The LDF used in this study has a 1-mW He–Ne laser with a wavelength of 632.8 nm. A straight probe (PF 416, Perimed) with a diameter of 2 mm was used to conduct a laser light beam of 125 μm (fiber to-fiber distance, 500 μm) to the measurement site within the dental pulp and to retrieve the backscattered light to the flowmeter. Prior to each measurement, the probe was calibrated for zero voltage and a motility standard of 250 PU using a plastic block (Perimed).

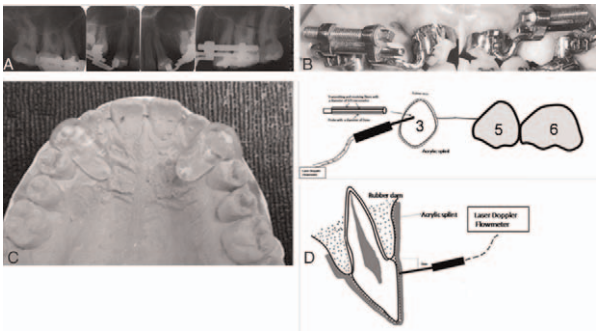

FIGURE 1. (A) Preoperative intraoral periapical radiographs. (B) Intraoral view of the dentoalveolar distraction device. (C) Photograph showing the splint design. (D) Schematic diagram of the measurement of pulpal blood flow.

Recording Procedures

Laser Doppler flowmetry was used to measure PBF of the 20 surgically distracted canines at baseline (within 1 week preoperatively, T0), at 4 days postoperatively (T1), at 7 days postoperatively (T2), at the end of distraction (between 11 and 14 days after surgery, T3) and at the end of the consolidation period (T4) and at parallel intervals for the nonsurgical control subjects. Unfortunately, PBF could not be measured immediately after surgery because the local anesthetic solutions that were used contain a vasoconstrictor that can lower PBF by prompting contraction of the vascular smooth muscles.[16] Accuracy and reproducibility of measurements were achieved by providing each patient with 2 custom-fabricated splints formulated from self-curing acrylic resin that were used to secure the probe in the appropriate positions approximately 3 mm from the gingival margin of each tooth, with 1 splint covering the crown of the right canine and the other covering the crown of the left canine (Fig. 1D). Each splint extended onto the palate and into the buccal sulcus and had a hole (2-mm diameter) over the labial surface of the tooth approximately 3 mm coronal to the gingival margin. Two splints were necessary because the fit of a single splint covering the 6 anterior teeth would be compromised by the distal movement of the distracted canines.

Prior to PBF measurement, the distraction device was temporarily removed, and a black rubber dam and both splints were positioned in the patient's mouth, and the patient was allowed to relax in the dental chair in a supine position for approximately 10 minutes. PBF was measured in both canine teeth during the same session; however, because only 1 probe was available, measurements were performed consecutively, with the probe remaining on 1 tooth for approximately 1 minute before being transferred to the contralateral tooth. All measurements were performed by the same operator (S.E.) under standardized environmental conditions at a constant room temperature. Attempts were made to minimize bias due to movement of subject and probe, and pulse rate and blood pressure were recorded throughout the measurement sessions. None of the participants reported any pain or discomfort during the

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procedure. After obtaining constant readings from both teeth, the splints and rubber dam were removed, and the distraction device was repositioned. For each measurement session, the mean PU for each tooth was calculated on the basis of the phase of stable values, excluding peaks attributable to movement artefacts. LDF data were transferred to a computer connected to the RS-232 port of the flowmeter using the system's own software (PeriSoft for Windows, Perimed) and stored for analysis at a later date.

Statistical Analysis

Statistical analysis was performed using MedCalc Statistical Software, Version 13.0 (MedCalc Software, Ostend, Belgium). Normal distribution of data was evaluated with a Shapiro Wilks test. Changes in PBF within and between groups were assessed using paired and Student *t* tests, respectively, with statistical significance set at $P < 0.05$.

RESULTS

Patients were clinically evaluated for immediate postoperative complications, time required for space closure, and amount of canine retraction. The distraction procedure was completed in 11 to 14 days (mean, 12.9 ± 0.93 days) at a rate of 0.5 mm/d. The mean amount of canine retraction was 6.5 ± 0.7 mm. Patients reported minimal-to-moderate discomfort, especially during the first 4 days after surgery; however, no pain was reported following activation of the distraction device, although some patients had complaints about the bulkiness of the device, and ulceration of the buccal mucosal was observed in 1 patient. No other postoperative complications related to the surgical procedure were observed.

Table 1 shows the maxillary canine PBF values at T0, T1, T2, T3, and T4 for both groups. Presurgical (T0) PBF values did not differ significantly between the study group (5.5+0.3 perfusion units [PU]) and the nonsurgical control group ($5.5 + 0.3$ PU) (P=0.892). No significant changes in PBF were observed in the control group over the course of the study; however, the mean PBF in the study group decreased significantly from T0 ($5.5 + 0.3$ PU) to T1 ($4.1 + 0.1$ PU, $P < 0.001$), was slightly higher at T2 ($5.0 + 0.1$ PU, $P < 0.001$), and had returned to the same levels measured prior to surgery at T3 ($5.5 + 0.3$ PU, $P < 0.001$). PBF did not vary between T3 and T4 ($P = 0.087$) or between T0 and T3 ($P = 0.189$) or T0 and T4 ($P = 0.070$) (Table 1). Although PBF varied significantly between the groups at T1 and T2, the differences between groups at T0, T3, and T4 were not statistically significant. The changes in canine PBF over time in the study group compared with the relatively constant PBF in the control group are illustrated in Figure 2.

DISCUSSION

The possibility of reducing orthodontic treatment time by accelerating tooth movement has attracted the interest of the orthodontic community in recent years. Surgically assisted rapid canine retraction is an extremely valuable technique to be considered in patients with severely crowded or protruded anterior teeth.[7–9] Canines can be rapidly distracted, and almost all the extraction space can be used for anterior dental alignment or retraction. Studies have proven rapid distraction of incisors using new bone tissue distal to the lateral incisors to be effective in reducing the duration of orthodontic treatment by 6 to 9 months in patients requiring extraction, thus eliminating the need for additional anchorage.[7–9]

TABLE 1. Maxillary Incisor PBF Values at T0, T1, T2, T3, and T4 for Each Group

Mean ± SD	T0	T1	T2	T3	T4
Study group	5.5 + 0,3	4.1 + 0.1	5.0 + 0.1	5.5 + 0.3	5.5 + 0.3
Control group	5.5 + 0,3	5.5 + 0.3	5.5 + 0.3	5.5 + 0.3	5.5 + 0.3
P^*	0.892	<0.001	<0.001	0.960	0.929

* Student *t* test.

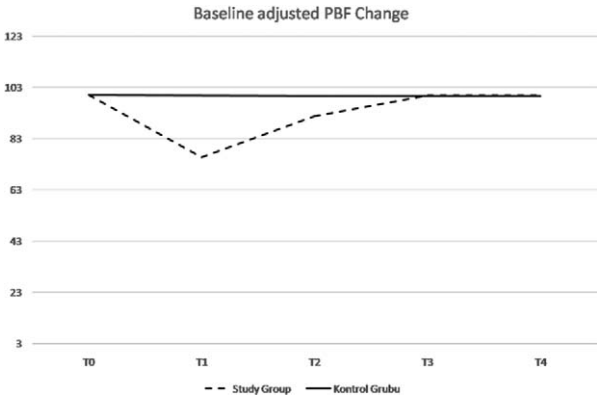

FIGURE 2. Changes in canine PBF over time in the study group compared with the relatively constant PBF in the control group are illustrated in the figure. PBF, pulpal blood flow.

This clinical study used LDF to evaluate maxillary-canine pulp vitality in 10 patients undergoing DD. Subjects were evaluated preoperatively (T0) and postoperatively during latency (T1), distraction (T2, T3) and 1 month following consolidation (T4). No differences were found in the baseline PBF values between the study and control groups. In addition, no significant mean change in PBF was observed in the control group over the course of the study, indicating that the change in PBF registered in subjects undergoing DD is unrelated to repeated measurement, flowmeter calibration, or test sensitivity. However, postsurgical PBF was significantly lower during the first week after the DD procedure in the study group when compared with the control group. The decrease in PBF in the study group was most noticeable during latency (T1), a period of 4 to 7 days between osteotomy and distraction. This significant decrease is most likely attributable to iatrogenic trauma caused by the osteotomy cuts around the canine root and other osteotomy-related factors such as heat generation, compression of adjacent tissue, and removal of the interdental bone as well as soft-tissue flap design. In addition, acute postoperative inflammation was still observable at Day 4 after surgery, causing vascular dilation in the soft tissue surrounding the osteotomy region, suggesting that the postoperative reduction in dental-pulp blood flow could be due to the phenomenon of "stealing," in which blood flow from the pulp is redirected to the localized swelling around the osteotomy region.[17] At day 7 postoperatively (T2), PBF was observed to have increased, and by the end of distraction (T3), PBF had returned to preoperative levels. Activation of the distraction device did not contribute to a reduction in PBF; on the contrary, PBF significantly increased during the distraction period. The recovery of PBF at the end of distraction is related mainly to the recovery of apical circulation resulted from the regeneration of blood vessels, and it makes possible to maintain an adequate blood supply and thus preserve canine vitality.[15] The recovery in PBF was further aided by the fact that only minimal force was needed to fully mobilize the dentoalveolar transport segment, including the canine tooth as well as the fact that the acute inflammatory reaction to surgery had subsided by T3 (11–14 days postsurgery). PBF showed no change from T3 to T4, the end of the consolidation period. The findings for PBF indicate that DD can be performed without endangering tooth vitality.

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Although the findings of the present study point to a brief phase of ischemia in which perfusion of the pulp tissue declines during the latency period, blood flow appears to return to normal by the end of distraction. The decrease in blood flow to the osteotomized segments during the latency period observed in the present study is supported by the vast majority of previous histological and animal studies.[18–21] For example, in 1 study,[21] LDF was used to measure blood flow in rats immediately following DO surgery to lengthen the tibia by 12.5%. Distraction began 5 minutes after wound-closure and was completed in 15 seconds, and LDF performed immediately upon completion of distraction found blood flow to the foot dorsum fell to 0.79 from a presurgical level of 2.03.[21] At the same time, the present study's finding that the decrease in PBF is only temporary and recovers completely by the end of distraction is also supported by numerous reports.[18–21]

The vast majority of DO studies have noted increased blood flow and vessel formation within the zone of distraction during the active distraction period.[22–26] An immunohistological study with rats identified a large number of new blood vessels along the interface of new bone accompanied by angiogenesis during the active distraction period;[22] based on these observations, the authors[22] suggested that these angiogenic events promoted bone repair and regeneration. Similarly, using a microarray analysis, Carvalho et al[25] demonstrated that the expression of angiogenesis-associated genes increased at the initial phase of distraction, suggesting their role as early mediators of vessel growth during distraction. In another study, microcomputed tomography was used to provide a quantitative 3-dimensional analysis of vascular networks of bone regenerate following mandibular DO in rats.[27] Vessels of all sizes were clearly visualized throughout the distracted regenerate, which was filled with contributions from the central medullary vessels as well as small vessels from surrounding periosteal networks in a uniformly distributed pattern.[27] Stereological analysis conducted as part of the same study also demonstrated robust and quantifiable increases in vascular density following DO. A scintigraphic study by Aronson and Shen[19] found blood flow in distracted long bones of dogs peaked 2 weeks after osteotomy, when it was approximately 8 times the level observed in controls, and then gradually decreased to predistraction levels after around 17 weeks. Immuno-histological analyses have similarly reported evidence of robust recruitment and sustenance of vascularity at the site of distraction long after the active distraction and consolidation phases have ended.[19,22,28] Unfortunately, physiological and/or methodological differences among studies make it difficult to correlate previous findings of postdistraction increases in blood flow and vessel formation with the findings of the present study.

Moreover, it may be wrong to simply extrapolate findings from within the zone of distraction and assume analogous events in the dental pulp. Certain distinctions are worth clarifying in this regard. Teeth present a unique environment for the blood supply, with all vessels entering and exiting the pulp through a single foramen or a relatively small number of foramina contained within a rigid compartment of dental hard tissue. Due to these unusual environmental constraints, dental pulp is frequently described as a low-compliance system in which any rise in tissue pressure will produce a corresponding decrease in afferent flow.[29]Dilation of arterioles due to inflammation could increase blood flow to the point where veins collapse under pressure, with subsequent poor venous drainage increasing hydrostatic tissue pressure, leading to ischemia and eventual necrosis.[29] In other words, if the same hypervascular episodes observed within the zone of distraction were to occur in dental pulp, an increase in PBF would lead to increased tissue pressure and ultimately to pulpal injury or death.

The orthodontic literature includes no study evaluating blood flow in human dental pulp following DD. However, in a study evaluating blood flow in human pulp following Le Fort I osteotomy and maxillary distraction, Harada et al[30] found mean PBF during Days 1 to 5 postsurgery had decreased to 40% to 50% of its preoperative value, but by 3 months postsurgery had increased to reach 59.5% of its preoperative value. Although the maxilla was not markedly advanced until 5 days postsurgery, considering that the Le Fort I osteotomy procedure was in itself extensive (including 10 teeth in the osteotomized segment as well as part of the descending palatine artery), the authors attributed the drop in PBF to surgical trauma. However, it would be wrong to compare the findings of that study[30] to those of the present study, which included only 1 canine tooth in the dentoalveolar transport segment and utilized minimal force to achieve full mobilization of the segment.

Distraction Methodology

Rapid canine-retraction in adult patients may be accomplished using 1 of 2 distraction methods: PD and DD. With PD, while the interseptal bone distal to the canine is undermined to weaken its resistance, a heavy force is still required to distract the canine toward the alveolar bone. Moreover, tissue and fibrous elements may become compromised during distraction with PD, most likely as a result of local injury to the periodontal ligament.[31,32] Excessive tensile force has been shown to decrease vascular supply in vitro, causing death to cells in the vicinity of the stretched periodontal ligament fibers.[33] Resorption of Sharpey's fibers, vascular invasion of cells into the periodontal membrane, resorption of alveolar bone, and reduction in alveolar bone thickness and height have also been shown to be inevitable in regions of tension.[32,33] In contrast to PD, DD utilizes the dentoalveolus itself as a bone-transport segment for posterior movement, with vertical corticotomies performed around the root of the canine teeth, followed by splitting of the surrounding spongious bone. Since this surgical technique does not rely on periodontal stretching, periodontal tissue is not subjected to stress accumulation or overload.[34] Movement of the tooth within the alveolar segment also eliminates the risk of harmful side effects to surrounding hard and soft tissue, and because mucosal incisions and osteotomies are made only on the vestibular side of the alveolar bone, with the gingival margin, palatal mucosa, and palatal bone left intact, the entire transport dentoalveolar segment, including the canine teeth, continues to receive an adequate supply of blood. A study that comparatively evaluated PD and DD noted PD to be a technique-sensitive, "blind" procedure characterized by a lack of access and visibility; moreover, in patients where the osteotomy procedure is inadequate or incomplete, the period required for canine retraction is lengthened to exceed the lag period, which can result in anchorage loss.[10] In contrast, DD provides excellent access, since all bony obstructions are efficiently removed, thus promoting retraction without any interference.[10] This comparative study using PD and DD yielded highly significant results giving the advantage to the finer surgical technique incorporating DD.[10] Given these findings, this study chose to perform rapid canine retraction using the DD technique.

The present study allowed for a 4-day latency period before a consolidation period of 4 weeks. The importance of a latency period for successful healing during distraction osteogenesis in the craniofacial region is still a matter of debate. Liou et al[35] demonstrated that the best time to initiate tooth movement in mature beagles was immediately after distraction, when the edentulous space is still fibrous and bone formation is just starting. However, due to the temporary disruption of blood vessels that is known to occur during the latency period, a few days of latency prior to the initiation of tension is considered essential for bone healing.[36] An early study by Ilizarov[20] that examined canine tibial long bones suggested that a latency period is required to allow for formation of a soft callus

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before active force is applied. In long bones of lambs, distraction performed immediately after osteotomy was shown to result in relatively less callus-tissue formation and poorer vascularization than osteotomy performed after a 10-day latency period.[37] Studies conducted with rabbit[38] and rat[39] mandibles also support the idea that a short latency period before the initiation of tension is essential for bone healing. Whereas distraction immediately following osteotomy was found to result in fibrous-tissue formation in the distraction gap, bone formation was observed when a 4-day latency period preceded osteotomy.[38–40]

In clinical situations, both the quality and quantity of regenerated bone are not only affected by surgical procedure and latency period, but also by the rate of distraction.[41] While a slow distraction rate is associated with premature consolidation, and a high rate fails to induce bone formation, leading to a fibrous union of bone segments,[41–43] moderate tension stimulates a cascade of biological processes, including cellular differentiation, angiogenesis, bone-matrix formation and mineralization, and bone remodeling.[22,23,28,42,44] Clinical studies have reported distraction rates for human mandibles to generally vary between 0.5 and 1.0 mm/day.[45–48] A study evaluating the distraction rate for vertical DO in the human mandible of elderly patients found more trabecular bone was produced using a slow distraction rate of 0.5 mm/day for 20 days rather than the standard rate of 1 mm/day for 10 days.[49] Blood-vessel formation during the early stages of bone formation was also higher with a distraction rate of 0.5 mm/day rather than 1 mm/day.[50] Therefore, a distraction rate of 0.5 mm/day was applied in the present study.

Laser Doppler Flowmetry Testing

Laser Doppler Flowmetry assessment of PBF is highly susceptible to patient-related factors such as stress, medication, and age and to environmental and technical factors such as flowmeter characteristics, gingival isolation device, ambient temperature, probe position, patient position, and rest status.[51–53] The present study's inclusion/exclusion criteria were designed to eliminate patient-related factors. To eliminate environmental and technical factors, custom-made acrylic-resin splints were used to stabilize the probe, maintain it in contact with teeth, and create reproducible positions for follow-up measurements, and an opaque, heavy-gauge rubber dam was used in conjunction with the splints so as to minimize the contribution of neighboring pulp and gingiva to the Flux signal. The same technique has been successfully employed in earlier studies.[54,55] Moreover, this study used a 632.8-nm laser source rather than a 780-nm or 810-nm laser because lasers with shorter wavelengths, while giving lower Flux readings (probably due to their lower degree of penetration through tooth tissue), are less likely to reduce the vital-to-nonvital signal ratio by including nonpulpal blood flow within the signal.[53] To further ensure the validity of measurements, special care was taken to maintain ambient temperatures and patient-related factors such as position, rest, and stress levels.

To eliminate possible problems associated with LDF measurements, PBF could not be measured during surgery because vasoconstrictor in local anesthetic, amount of haemorrhage, stress level, and mainly difficulty in splint and rubber-dam application intraoperatively and therefore signal contamination with back-scattered light from nonpulpal tissues, such as gingival and periodontal tissues effect the sensitivity limitation of the LDF.[16,51,54] Furthermore, contralateral canines in the same subject could not be used as control teeth because both left and right canines were being treated for malocclusion. Therefore, canines from different patients were used as controls. While the nonsurgical control group was included to account for temporal variability that may occur with repeated blood-flow measurements,[14] extrapolation of results to the experimental canines may be problematic, considering the numerous patient-related biological characteristics that can influence pulpal response. On the other hand, with a split-mouth design, the possibility of a spill-over effect of distraction forces through the archwire to the control canine cannot be excluded.

CONCLUSIONS

During the latency period of DD there appears to be a phase of ischemia where perfusion of the pulp tissue declines, but this period is of short duration, and blood flow apparently returns to normal at the end of distraction. These findings suggest that PBF is well maintained following DD, making it possible to perform this procedure without compromising the vascular supply to the maxillary canines.

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