Pulp blood flow and sensibility in patients with a history of dental trauma undergoing maxillary expansion: *A prospective study*

Raymond Lam[a]; Mithran S. Goonewardene[b]; Steven Naoum[c]

ABSTRACT

Objectives: To assess changes in pulp blood flow (PBF) and pulp sensibility (PS) in teeth of patients with a history of dental trauma undergoing maxillary expansion.

Materials and Methods: Twenty-five patients requiring rapid maxillary expansion (RME) had the pulp status of their maxillary anterior teeth assessed using laser Doppler flowmetry, electric pulp testing, and thermal testing (CO2 snow). Each patient was tested at T1 (prior to expansion), T2 (2 weeks after rapid expansion), and T3 (3 months after expansion). Relationships between PBF, time interval, and history of trauma were evaluated using linear mixed modelling.

Results: Within the Trauma group, PBF was significantly lower ($P \leq .05$) at T2 and T3 in comparison to T1 and significantly lower ($P \leq .05$) at T2 in comparison to T3. In the Non-trauma group, PBF at T2 was significantly lower ($P \leq .05$) than PBF at T1 and T3; however, no significant difference ($P > .05$) in PBF was observed when comparing PBF at T1 and T3. In both groups, PS was maintained in almost all teeth (>90%).

Conclusions: RME in healthy teeth causes reduction of PBF before reestablishment of pretreatment values. RME in traumatized teeth causes reduction of PBF without PBF being reestablished to pretreatment levels. Teeth with a history of compromise may have reduced adaptive capacity under insults such as RME, which should be appreciated during the informed consent process. (*Angle Orthod.* 2020;90:695–701.)

KEY WORDS: Maxillary expansion; Trauma; Pulp status; Hyrax expander

INTRODUCTION

Maxillary transverse deficiency is a frequent problem encountered in orthodontics, with estimations[1–3] indicating that almost a third of patients exhibit a component of this disharmony. Treatment need for these problems extends beyond esthetic requests, as a subset of these malocclusions are accompanied by posterior crossbites, which may result in mandibular displacement and skeletal asymmetry.[4,5] In prepubertal patients, rapid maxillary expansion (RME) was shown[6] to be effective in managing transverse issues related to a narrow maxilla.

Forces produced from RME were shown[7] to range from 7.54 to 15.8 kg. Reported undesirable side effects of RME include tipping of the buccal segments, cortex fenestration, dehiscence, and gingival recession. These effects have been observed under finite element modelling, demonstrating that all maxillary teeth are subjected to expansive forces and forces from stretch of the mucoperiosteal tissues, to varying degrees.[8,9]

Several studies using conventional and specialized tools such as carbon dioxide cold testing (CO2), electric pulp testing (EPT), and laser Doppler flowmetry (LDF) demonstrated that RME was not detrimental to the pulp. Babacan et al.[10] reported a reduction in pulp blood flow (PBF) during maxillary

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expansion, with eventual recovery to pretreatment values. This was consistent with the findings of other studies[11,12] examining RME using similar methods. As such, when used appropriately, RME is a predictable and safe procedure, a testament to its long history of use.

While these findings are welcoming, there is one key consideration that requires greater examination. An important issue is the impact on PBF in teeth demonstrating a history of trauma. Previous PBF studies involving maxillary expansion have focused on sound, healthy, and asymptomatic teeth; teeth with a history of trauma, caries, restorative, and/or periodontal disease have been specifically excluded. The absence of this important data was highlighted in a review by Javed et al.,[13] who stated that "there is insufficient validation regarding the association between orthodontic forces and pulp vitality . . . a history of dental trauma is a risk factor for loss of pulp vitality during orthodontic treatment." The impact of dental trauma is unpredictable, and despite the best preventive strategies, no individual is at zero risk in terms of the routine activities of daily living.

On a global level, approximately one-third of children/toddlers and one-fifth of adolescent/adults have experienced dental trauma.[14,15] Of particular importance to the orthodontist is that the peak risk periods for sustaining trauma coincide with the time during which the circummaxillary sutures are most amenable to separation and, therefore with a common time for the prescription of RME.[16,17] As such, it is not uncommon for patients seeking orthodontic treatment to present with traumatized teeth or to be at risk of sustaining trauma during the course of treatment.[15]

The premise that traumatized teeth undergo irreversible cellular changes has been demonstrated histologically. Several studies investigated the effects of RME forces on the pulp of virgin teeth. Despite reversible vascular changes from expansive forces, Kayhan et al.[18] noted persistent fibrotic changes and degenerative vessel walls after 3 months of RME. Similarly, Taspinar et al.[19] reported slight persistent fibrotic changes, despite most parameters reaching equivalency, to their control group after 18 months. The premise that traumatized teeth have reduced adaptive capacity when subjected to high forces in RME, therefore, seems likely. Despite this, the significance of these changes toward the long-term prognosis of teeth is not well understood, but there are indications that irreversible subclinical changes may occur.

Should a reduction in pulp blood flow occur in traumatized teeth beyond their adaptive capacity, necrosis of the pulp is a potential sequalae. As such, the aim of this study was to assess changes in PBF and pulp sensibility (PS) in traumatized and healthy teeth in patients undergoing maxillary expansion.

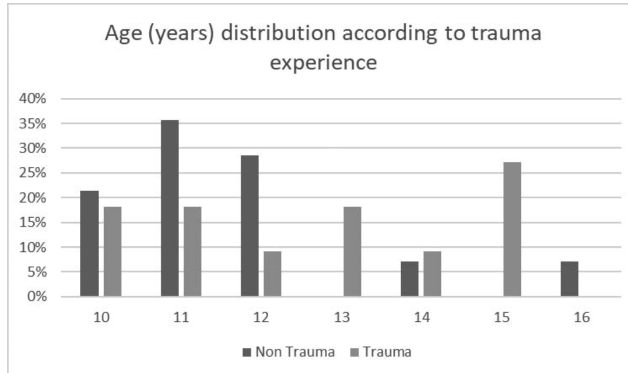

Figure 1. Age distribution of sample according to trauma experience.

MATERIALS AND METHODS

This study was a single-center, prospective study conducted at the Oral Health Centre of Western Australia during the 2018–2019 period. Ethical approval was obtained from the Human Research Ethics Committee at the University of Western Australia (RA/4/20/4611).

At the commencement of 2018, all newly consented treatment plans were assessed. Patients requiring RME as part of their orthodontic treatment were identified and invited to participate. Analyses of pretreatment records, including history taking, radiographs, photographs, and clinical notes, were assessed to identify teeth with compromise. This provided a tooth-level analysis through which two groups were established: Trauma and Non-trauma groups. Non-trauma teeth were asymptomatic, pathology-free virgin teeth with no history of trauma or restorative dentistry. Teeth in the Trauma group included teeth with the following characteristics: impact injuries, as defined by Andreasen et al.[20]; and teeth with pathologic tooth loss and/or restorative intervention. In total, 25 patients (mean age = 12 years; range, 10–16 years) were included in the study, with 11 patients (44%) having experienced trauma.

Age characteristics of the patients experiencing trauma are shown in Figure 1. The nature of injuries is shown in Figure 2. Severe injuries resulting in tooth loss or teeth requiring root canal therapy were excluded, as these teeth were not suitable for testing. Table 1 demonstrates tooth-level characteristics in the study. Post-review (after 3 months post–initial expansion [T3]) of all subjects indicated that the desired amount of expansion was achieved in all cases.

Participants were then followed prospectively over three time intervals, defined as T1, T2, and T3, with the following expansion protocol:

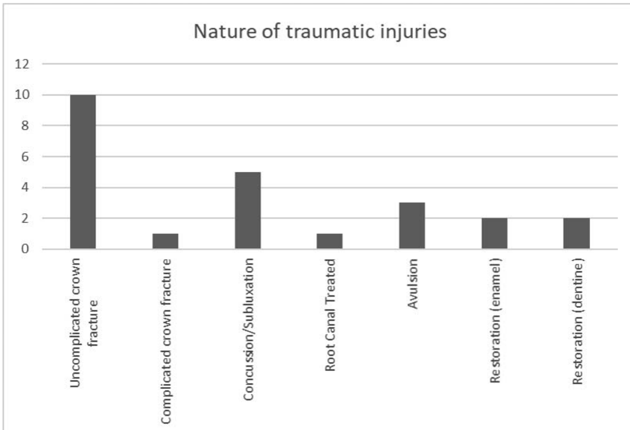

Figure 2. Classification of traumatized teeth according to nature of insult.

Table 1. Sample Summary

	Frequency, No.	Percentage
Patients	25	
Teeth	124	
Sex		
Male	9	36
Female	16	64
Group		
Non-trauma	101	81
Trauma	23	19
Tooth		
11	24	19.35
12	25	20.16
13	13	10.48
21	24	19.35
22	24	19.35
23	14	11.29

1) T1: Prior to expansion
   - Days 1–3: 0.5 mm/d
   - Days 4–10: 0.25 mm/d
   - Day 11 onward: 0.25 mm/3.5 d until desired expansion
2) T2: Ten days after initial expansion (nonactivation day)
3) T3: Three months after initial expansion (retention period, no activation).

As such, days 1 through 10 constituted the period of rapid expansion. The median amount of expansion approximated 6 mm in both groups. Each participant was expanded using a hyrax appliance, with bands placed on upper first molars and occlusal rests placed on either the first premolar or first primary molar.

All permanent anterior teeth, when present, were tested in the study for two reasons. First, as the main consideration in this study was trauma, these teeth provided the greatest opportunity to assess the relationship between trauma and PBF. Second, bands on posterior teeth to support the hyrax appliance did not permit the use of jigs. Teeth excluded from the study included missing teeth due to avulsion or agenesis, root-filled teeth, and impacted and unerupted canines.

A laser Doppler flowmeter (MoorLABTM/FloLABTM, Moor Instruments Ltd, Axminster, UK), zeroed against a static reflector and calibrated using Brownian motion medium, was used to measure PBF. The laser exhibited a wavelength of 780 nm and a primary band with a frequency of 3.1 KHz set to 0.1-second time output constant. Individual, custom, soft-lined acrylic splints were prepared for each tooth (Figure 3). The center of the cylinder was positioned 3 mm from the gingival margin of each tooth. During PBF measurement, the LDF probe was inserted into the metal cylinder of each splint to make contact with the buccal surface of the tooth being assessed. The splint ensured accuracy, stability, and reproducibility of probe position. Patients were rested in the supine position for 3 minutes before testing. Customized software (LAB-SOFTTM, Moor Instruments) was used to record data; this consisted of a flux reading in perfusion units (PUs).

EPT (Vitality Scanner 2006, Kerr Endodontics, Orange, Calif) and CO2 (Odontotest; Fricar A.G., Zurich, Switzerland) were employed to assess pulp sensibility. For EPT, the assessment probe was placed on the buccal surface of each tooth until a patient response was elicited or until the voltage reached a value of 80. A recording of 1 to 79 correlated to a positive response, whereas a recording of 80 was negative. Carbon dioxide attained from a pressurized cylinder containing liquid carbon dioxide was collected in a thin plexiglass tube of 3.5-mm diameter as CO2 snow. The snow was applied to the center of the buccal surface of each assessed tooth for up to 10 seconds, unless a patient's response to the stimulus was attained. Responses to the CO2 test were recorded as either "positive" or "negative"; a negative response

Figure 3. Customized acrylic splints.

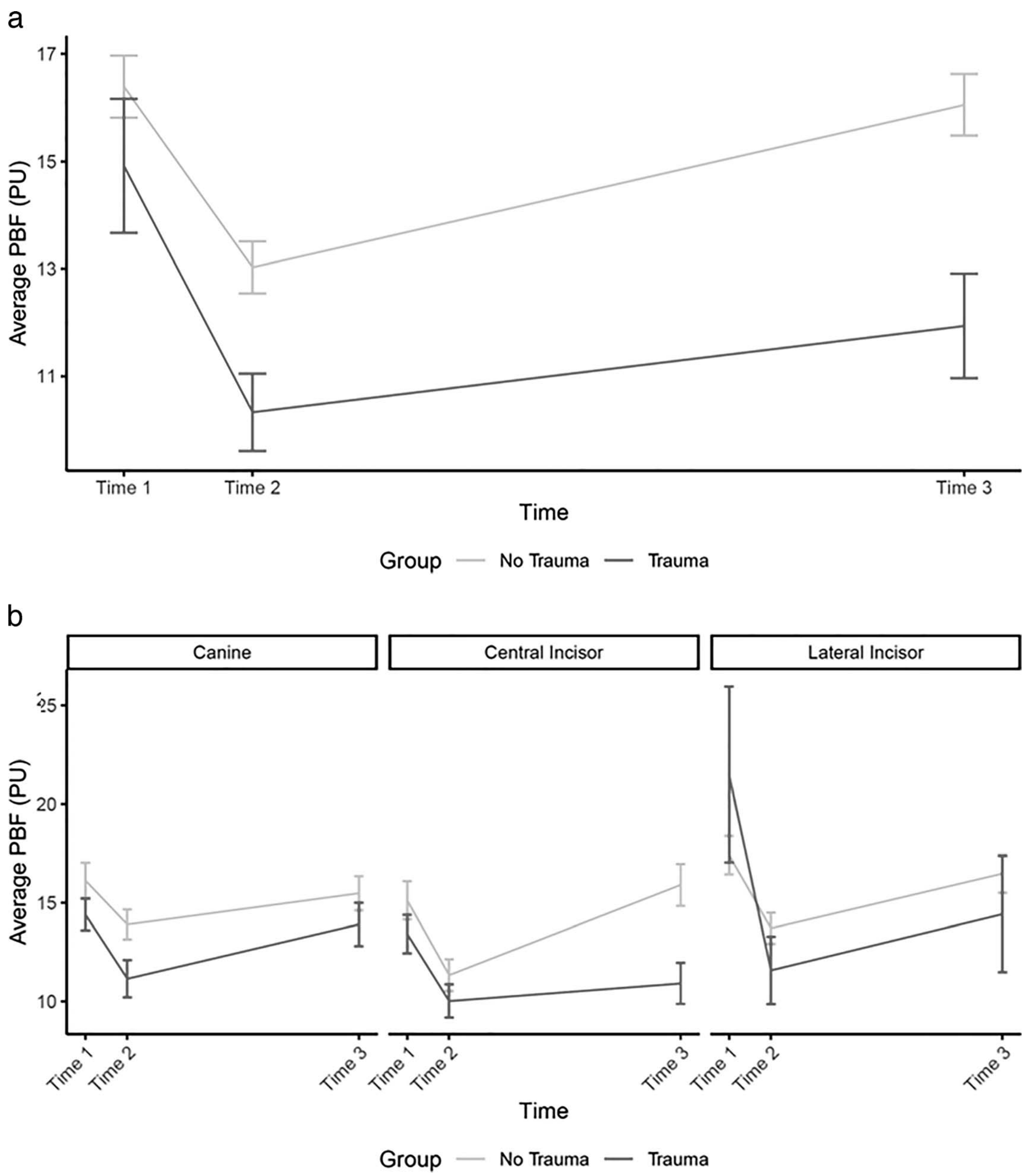

Figure 4. PBF (PU units) by tooth type, with standard error bars, at each assessment time for Trauma and Non-trauma groups.

was recorded if the patient did not respond to the stimulus during two consecutive tests in the single assessment appointment.

Linear mixed models were used to investigate the relationship between PBF over time and trauma/non-traumatized teeth. Data were analyzed using the R environment for statistical computing.[21]

RESULTS

Figure 4 displays average PBF within the maxillary anterior teeth for the Trauma and Non-trauma groups. Prestudy equivalence in PBF was apparent between the two groups. There was no statistically significant difference ($P > .05$) in PBF between the Trauma and Non-trauma groups at T1. Within the Trauma group, PBF was significantly lower ($P \leq .05$) at T2 and T3 in comparison to T1 and significantly lower ($P \leq .05$) at T2 in comparison to T3. In the Non-trauma group, PBF at T2 was significantly lower ($P \leq .05$) than PBF at T1 and T3, but there was no significant difference ($P >$ .05) in PBF when comparing T1 and T3.

Table 2 displays the estimated mean difference (MD) from mixed modelling for the Trauma and Non-trauma groups at each time point. There was no statistically significant difference ($P > .05$) between the two groups at T1. However, at T2 and T3 there was a statistically

Table 2. Pairwise Comparison Between Groups at Each Timepoint[a]

	Non-trauma–Trauma		
	Estimate	95% CI	*P* Value
T1	1.503	−0.881, 3.886	.215
T2	2.656	0.272, 5.039	.029
T3	4.286	1.902, 6.669	<.001

[a] CI indicates confidence interval; T1, prior to expansion); T2, 2 weeks after rapid expansion; and T3, 3 months after expansion.

significant difference ($P \leq .05$) in PBF between the Trauma and Non-trauma groups. At T2, teeth without trauma had a significantly higher PBF in comparison to teeth with trauma (MD = 2.656, 95% confidence interval [CI] = 0.272, 5.039, $P = .029$); the same was observed at T3 (MD = 4.286, 95% CI = 1.902, 6.669, $P = <.001$).

Table 3 displays the results comparing PBF at different time points for both groups. For the trauma group, PBF at both T2 and T3 was significantly lower than at T1; T1–T2 (MD = 4.517, 95% CI = 3.131, 5.904, $P = <.001$) and T2–T3 (MD = 3.122, 95% CI = 1.735, 4.508, $P = <.001$). For the trauma group, PBF at T2 was also significantly lower than at T3 (MD = –1.396, 95% CI = –2.782, –0.009, $P = .048$). For the Non-trauma group, the PBF at T2 was significantly lower than at T1 (MD = 3.364, 95% CI = 2.703, 4.026, $P = <.001$). The PBF at T2 was significantly lower than at T3 (MD = –3.026, 95% CI = –3.687, –2.364, $P = <.001$). However, the PBF for the Non-trauma group was not significantly different between T1 and T3 ($P > .05$).

Most teeth in both groups (>90%) maintained pulp sensibility during expansion, regardless of whether there was a history of previous trauma (Figure 5).

DISCUSSION

Since RME is a common procedure performed in orthodontics, one during which significant forces are utilized, deleterious effects of RME on dental and periodontal tissues are possible. The present study assessed the pulp status of teeth with a history of trauma during maxillary expansion, a subject that had not been previously investigated.

Table 3. Pairwise Comparison Among Timepoints for Each Group[a]

	Trauma		
	Estimate	95% CI	*P* Value
T1–T2	4.517	3.131, 5.904	<.001
T1–T3	3.122	1.735, 4.508	<.001
T2–T3	−1.396	−2.782, −0.009	.048
	Non-trauma		
	Estimate	95% CI	*P* Value
T1-T2	3.364	2.703, 4.026	<.001
T1–T3	0.339	−0.323, 1.000	.314
T2–T3	−3.026	−3.687, −2.364	<.001

[a] CI indicates confidence interval; T1, prior to expansion); T2, 2 weeks after rapid expansion; and T3, 3 months after expansion.

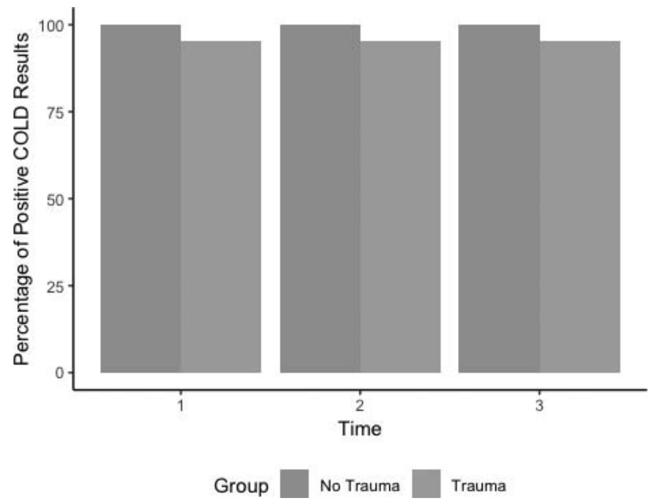

Figure 5. Percentage of teeth that underwent CO2/EPT testing and were recorded as positive at each time interval.

Pulp Blood Flow

The results from the Non-trauma group were consistent with previous reports indicating that PBF declined following maxillary expansion but eventually recovered to pretreatment values. Although the final reported PBF at T3 in this study was consistent with that noted in published research,[10,12] PBF changes between initial expansion and final review differed from those reported by Babacan et al.[10] They reported an initial increase in PBF immediately following expansion, followed by a gradual return to pretreatment PBF.[10] The observed increase in PBF was attributed to inflammatory-mediated increases as a result of expansive forces.[10] The discrepancy with the findings in the present study may be attributed to the difference in reporting frequencies. In the present study, T2 was taken at 2 weeks after initial expansion, whereas Babacan et al.[10] recorded PBF within the first week. Over this increased time period, a reduction in PBF may have occurred as a result of any combination of the known side effects of RME, including alveolar bone bending, periodontal ligament compression, tension in the muco-gingivae, and/or vascular constriction. Although these changes may be conceptualized to be more pronounced in anchored teeth, which were in the direct line of action to expansive forces, anterior teeth also have the capacity to be affected by these processes.

Notably, no previous study has considered the effect of RME on compromised teeth. A finding of clinical relevance from the present study was that PBF within traumatized teeth did not return to preexpansion values, as has been reported[10,12] for nontraumatized teeth. Despite this, at no point did PBF fall to zero. PBF reduction corresponded well with the findings of histological studies,[18,19] in which fibrotic changes appeared long after the removal of forces, hinting that irreversible cellular changes may occur subclinically.

Pulp Sensibility

The observation that more teeth failed to respond to EPT compared to CO2 snow, both before and after expansion, was consistent with the findings of previous studies[22–24] reporting that EPT was a less-reliable measure of pulp sensibility than CO2 snow for teeth with immature apices. Despite this, the differences between both tests in this study were small and insignificant. A key finding was that despite regressive changes in pulp blood flow being observed, pulp sensibility was maintained throughout the study for the majority of teeth.

Limitations

The sample size of traumatized teeth did not permit a more in-depth analysis of the severity of compromise with adequate statistical power. It is well known that the incidence of pulp necrosis for certain traumatic injuries offers a worse prognosis than do more subtle injuries. Additionally, teeth with severe injuries resulting in tooth loss (avulsion) or those requiring root canal therapy as a result of trauma were excluded from this study, as they were not amenable to testing. It is also reasonable to assume that orthodontic treatment would not have been initiated if patients had experienced trauma-related pain. As such, the traumatic injuries in this study tended to be milder. There was also a discrepancy between the numbers of traumatized and nontraumatized teeth. This was unsurprising and reflected the prevalence and incidence of trauma reported from epidemiological studies indicating that approximately one in five adolescents experienced at least one traumatic dental injury.[15]

Another limitation was the time period during which this study was conducted. Ideally, a period of observation extending beyond 3 months would have been employed. While insightful, the principal aim of this study was to assess PBF changes in traumatized teeth, rather than focusing on long-term outcomes.

Tooth-specific factors encountered during this study were not reported as a result of limited statistical power. Pulp flow changes may be more pronounced in teeth with greater movements. Physiological changes in the pulp, such as pulp canal calcification and apical migration of the root canal system, may have occurred in traumatized teeth. Despite this, the location of testing via the placement of the jigs was maintained for consistency. Although these factors were expected to influence PBF, the focus of this study was to determine the relative changes in PBF at defined time intervals for each tooth with its given circumstances.

CONCLUSIONS

- For healthy teeth, RME causes reduction of PBF before reestablishment to pretreatment PBF by 3 months.
- For traumatized and/or compromised teeth, RME causes reduction in PBF. However, PBF does not reach pretreatment levels by 3 months.
- Pulp sensibility is maintained during RME in healthy and compromised teeth. Thus, the use of pulp sensibility testing alone to determine pulp health should be approached with caution.
- Traumatized teeth may have reduced adaptive capacity under further insults, such as RME, which should be appreciated during the informed consent process.

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