

ORIGINAL ARTICLE

Changes in maxillary incisor dental pulp blood flow during intrusion by mini-implants

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Abstract

Aim. The aim of this clinical study was to identify changes in pulpal blood flow (PBF) in human central incisors resulting from short- and long-term intrusive orthodontic forces from mini-implants. **Materials and methods.** A total of 40 sound upper central and lateral incisors in 20 patients scheduled for intrusion for orthodontic reasons were divided into two groups. From each group, 20 teeth were subjected to intrusive force from mini-implants (Group 1 = Light Force: 40 g; Group 2 = Heavy Force: 120 g), whereas the remaining 20 contralateral teeth were not subjected to forces from mini-implants and served as controls. Laser-Doppler flowmetry (LDF) measurements were recorded at baseline and at 3 days and 3 weeks following intrusion. **Results.** PBF decreased significantly at 3 days (Light Force Group: 7.72 ± 0.50 ; Heavy Force Group: 7.72 ± 0.52) and then increased towards baseline at 3 weeks (Light Force Group: 10.37 ± 0.58 ; Heavy Force Group: 10.31 ± 0.45) following intrusion. **Conclusions.** In other words, despite slight regressive changes in pulpal tissue in the short-term, PBF improved after 3 weeks following intrusion by mini-implants, indicating that the changes observed in PBF is reversible, even following radical incisor intrusion.

Key Words: PBF, pulp tissue, LDF, intrusion, mini-implant.

Introduction

Orthodontic forces are known to produce mechanical damage and inflammatory reaction in the periodontium as well as cell damage, inflammatory changes and circulatory disturbances in dental pulp [1]. Several studies have suggested that orthodontic forces can adversely affect pulpal microcirculation [1–5]. However, convincing data demonstrating actual changes occurring in pulp microvasculature after application of orthodontic force is lacking. Pulpal response following the application of orthodontic force may be evaluated through histological observation [2], fluorescent microsphere injection [3] and measurement of pulp tissue respiration rates [4]; however, all these methods may only be applied following tooth extraction. In contrast, laser Doppler flowmetry (LDF) is a non-invasive method of performing repeated measurements of pulpal blood flow (PBF) without causing damage to the pulp [5].

Of the different orthodontic forces applied to mature teeth, intrusion, which is often performed to treat moderate-to-severe deep-bite, is considered one of the most damaging to tooth pulp. Changes in pulpal tissue are believed to result in part due to the compression force on periapical blood vessels created by the apical displacement of the tooth [6]. Over the years, various approaches for intruding incisor teeth and controlling overbite have been developed, including utility arches, extra-oral appliances and maxillo-facial surgery, among others [7]. While they are all viable treatment modalities, most are limited by factors such as force control and patient compliance that directly affect treatment results. Recently, fixed-anchorage devices including osseointegrated dental implants, titanium mini-plates and mini-implants have been introduced to control orthodontic forces and intrusion [8]. Unfortunately, osseointegrated dental implants and titanium mini-plates require more extensive, often surgical, intervention for placement and removal, which precludes their use in many

patients. Of all fixed-anchorage devices currently available for intrusion, mini-implants are the least invasive, most conservative in terms of placement and removal, most flexible with respect to implantation site selection and least expensive. Mini-implants are especially well-suited for non-compliant patients and are esthetically more acceptable than extra-oral appliances.

Only a few published studies have evaluated PDF changes in relation to specific intrusion forces [6,9]. Sano et al. [6] evaluated PBF parameters in permanent maxillary left central incisors of patients undergoing utility arch intrusion and Barwick and Ramsay [9], in examining the effects of brief intrusive force on pulp, reported reversible vascular changes. While both these studies suggest that the intrusive forces applied by utility arches can cause either reversible or irreversible changes in dental pulp [6,9], there is no published clinical study examining changes in PBF during orthodontic intrusion by mini-implants. Therefore, this *in vivo* study aimed to use LDF to measure PBF of incisors at baseline, 3 days and 3 weeks following orthodontic intrusion using mini-implants with different magnitudes of intrusive force and to identify and compare any differences in blood flow related to amount of force, duration of intrusion and tooth type.

Materials and methods

Subjects and intrusive force application

This study was approved by the Institutional Review Board and Ethics Committee of the Ministry of Health's Kecioren Training and Research Hospital (B.10.4.ISM.4.06.68.49) and complied with the principles of the Helsinki Declaration. Informed consent was obtained from all participants. In total, 20 healthy patients (age 18–25 years; mean age: 20.3 years) with deep bite of 4 mm or more were selected for participation from among the patients applying to the hospital for treatment. The initial intra-oral periapical radiographs were taken and patients with missing teeth in the maxillary anterior area, a history of trauma, root canal treatment, caries, restoration or previous orthodontic treatment and excessive gingival display were excluded from the study. Study participants were randomly divided into two groups ($n = 10$) according to the level of force applied. In Group 1 (Light), intrusive force of 40 g was applied to the maxillary left central and lateral incisors and, in Group 2 (Heavy), intrusive force of 120 g was applied to the same teeth, whereas no force was applied to the contra-lateral incisors, which served as controls. Force was applied by means of a mini-implant inserted according to the following procedures:

Metal brackets (0.018×0.025 inch) were bonded to maxillary anterior teeth. Leveling was performed

using a segmental arch. As soon as an 0.016×0.022 -inch stainless-steel segmental arch could be inserted as a rigid segmental anterior unit, a self-drilling mini-implant (diameter = 1.3 mm; length = 5 mm; Absoanchor, Dentos, Daegu, South Korea) was inserted into the alveolar bone between the roots of the maxillary left central and lateral incisors at the mucogingival junction. A standard periapical radiograph was taken to check the position of the mini-implant in relation to the neighboring roots. Intrusion force was delivered by a nickel-titanium closed-coil spring (3M Unitek, Monrovia, CA) placed between the hooks of the passive arch and the mini-implants, with force maintained at either 40 g (Light) or 120 g (Heavy). Mini-implants were loaded immediately after insertion, and the magnitude of the intrusive force was checked and calibrated using a gram-force gauge (Correx; Ortho Care, Saltaire, UK) during initial activation (baseline) and prior to LDF evaluation at 3 days and 3 weeks [10]. After 3 weeks, intrusion with a mini-implant was initiated in the control group and the overall treatment was terminated when an appropriate upper lip-to-incisor relation and optimal overbite were achieved (mean treatment time = 5–6 months); including follow-up, treatment lasted a total of 9 months.

Laser doppler flowmeter

PBF was measured using a Laser Doppler Flowmeter (Periflux PF 4001, Perimed, Järfälla, Sweden), which records amounts of backscattered light. The LDF output signal voltage is linearly related to red-blood-cell flow (number of cells \times 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 (Perimed) using a plastic block (Perimed).

Recording procedures

LDF measurements were recorded just prior to intrusion (T0), at day 3 of intrusion (T1); and at week 3 of intrusion (T2). Accuracy and reproducibility of measurements was achieved by providing each patient with a custom-fabricated splint of self-curing acrylic resin that was used to secure the probe in the appropriate position between the gingival margin and the orthodontic bracket (Figure 1). Patients were allowed to rest in a supine position in the dental chair for ~10 min, after which the splints were placed on the

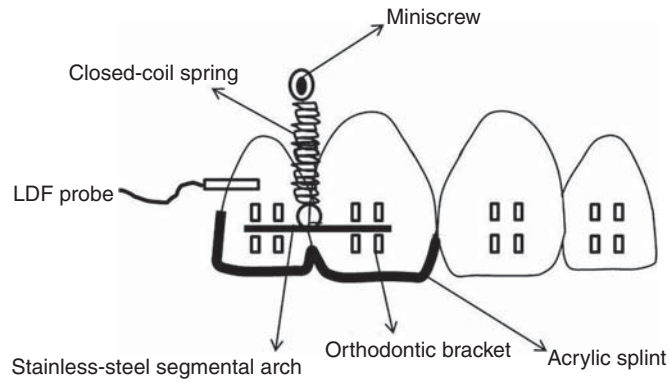


Figure 1. Schematic drawing of the mini-implant and LDF probe (frontal view).

teeth and the lips were retracted using cotton rolls. LDF measurements were continuously recorded for each tooth (experimental incisors as well as controls) until 2 min of stable PBF data values were registered on the flowmeter screen. All measurements were performed by the same operator under standard environmental conditions at a constant room temperature. Attempts were made to minimize bias due to movement of subjects 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 procedure.

For each session, mean PUs for teeth were calculated for the phase of stable values, with peaks attributable to movement artefacts excluded. Data recorded by LDF was 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

Data was analyzed using SPSS 11.5 for Windows (SPSS Inc., Chicago, IL). Repeated measures analysis of variance (ANOVA) with Bonferroni correction was used to test for differences in PBF measurements by time, with a level of $p < 0.001$ considered statistically significant. Student's t -test was used to test for differences in PBF measurements by level of force, and student's paired t -tests were used to test for differences in PBF measurements by tooth type (central and lateral incisor), with levels of $p < 0.05$ considered

Table I. ROC analysis.

Test result variable(s)	Area	SE ^a	Asymptotic Sig ^b	Asymptotic 95% CI	
				Lower Bound	Upper Bound
Group 1					
Lateral (T0)	0.560	0.133	0.650	0.300	0.820
Central	0.700	0.119	0.131	0.467	0.933
Lateral (T1)	1.000	0.000	0.000	1.000	1.000
Central	1.000	0.000	0.000	1.000	1.000
Lateral (T2)	0.070	0.058	0.001	0.000	0.184
Central	0.920	0.065	0.001	0.792	1.000
Group 2					
Lateral (T0)	0.525	0.134	0.850	0.263	0.787
Central	0.550	0.134	0.705	0.288	0.812
Lateral (T1)	1.000	0.000	0.000	1.000	1.000
Central	1.000	0.000	0.000	1.000	1.000
Lateral (T2)	0.880	0.084	0.004	0.715	1.000
Central	0.930	0.063	0.001	0.807	1.000

The test result variable(s): Group 2 lateral (T0) has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

^aUnder the non-parametric assumption.

^bNull hypothesis: true area = 0.5.

Table II. PBF measurements during the observation periods and comparisons of session-related variances.

Forces	T ₀	T ₁	T ₂	p-value ^a	Pairwise comparisons ^b		
					T ₀ -T ₁	T ₀ -T ₂	T ₁ -T ₂
Light intrusive force group (40 g)							
Control (n = 20)	11.74 ± 0.94	11.88 ± 0.96	11.94 ± 0.92	0.651	—	—	—
Experimental (n = 20)	11.36 ± 0.92	7.72 ± 0.50	10.37 ± 0.58	< 0.001	p < 0.001	p = 0.060	p < 0.001
Heavy intrusive force group (120 g)							
Control (n = 20)	11.55 ± 0.82	11.88 ± 0.88	11.76 ± 0.96	0.355	—	—	—
Experimental (n = 20)	11.47 ± 0.89	7.72 ± 0.52	10.31 ± 0.45	< 0.001	p < 0.001	p = 0.005	p < 0.001

Recording sessions T0: just before intrusion; T1: at the 3rd day of intrusion; T2: at the 3rd weeks of intrusion.

^aRepeated measurements of ANOVA.

^bBonferroni Adjusted Pairwise Comparisons.

statistically significant. Also, area under the curve was calculated using ROC analysis to see if the measurements have an ability to distinguish between the two groups (Table I).

Results

Mean PBF values are summarized in Tables II and III. No significant differences were found among the mean PBF values of any of the groups at baseline (Student's *t*-test, $p = 0.641$, $p = 0.789$). No significant changes in PBF were observed in the control group over the course of the study; however, when compared to their baseline values, PBF values at day 3 of intrusion were significantly lower for both experimental groups ($p < 0.001$) (Figure 2). Moreover, PBF levels for both experimental groups tended to return towards baseline after 3 weeks; thus, the PBF measurements of both experimental groups were significantly lower after 3 days of intrusion when compared to 3 weeks of intrusion, but the difference in PBF values at baseline and 3 weeks did not differ significantly. No significant differences were observed

between mean PBF values of the two experimental groups at any of the observation times.

No significant differences between mean PBF values of upper central and lateral incisors were observed at any of the observation times. However, PBF decreased significantly at 3 days of intrusion for both central (7.84 ± 0.55) and lateral (7.60 ± 0.54) incisors and then increased towards baseline values at 3 weeks of intrusion (10.39 ± 0.50 and 10.29 ± 0.63 for central and lateral incisors, respectively) (Figure 3). The amount of change in PBF from baseline to 3 weeks did not differ significantly among any of the groups. Furthermore, no tooth discoloration, pulpal necrosis or root resorption was observed.

Discussion

The results of this study show that intrusive orthodontic forces can affect blood supply to dental pulp. However, although an initial significant decrease in PBF values was observed after the brief application of intrusive force, this was eventually followed by a pattern of gradual recovery over time and, although PBF did not return to initial baseline levels for either

Table III. PBF measurements during the observation periods and comparisons of force-related variances.

Forces	Light intrusive force	Heavy intrusive force	p-value ^a
Control			
T ₀	11.74 ± 0.94	11.55 ± 0.82	0.641
T ₁	11.88 ± 0.96	11.88 ± 0.88	0.996
T ₂	11.94 ± 0.92	11.76 ± 0.96	0.678
Experimental			
T ₀	11.36 ± 0.92	11.47 ± 0.89	0.789
T ₁	7.72 ± 0.50	7.72 ± 0.52	0.993
T ₂	10.37 ± 0.58	10.31 ± 0.45	0.796

Recording sessions T0: just before intrusion; T1: at the 3rd day of intrusion; T2: at the 3rd weeks of intrusion.

^aStudent's *t*-test (Student's *t*-test).

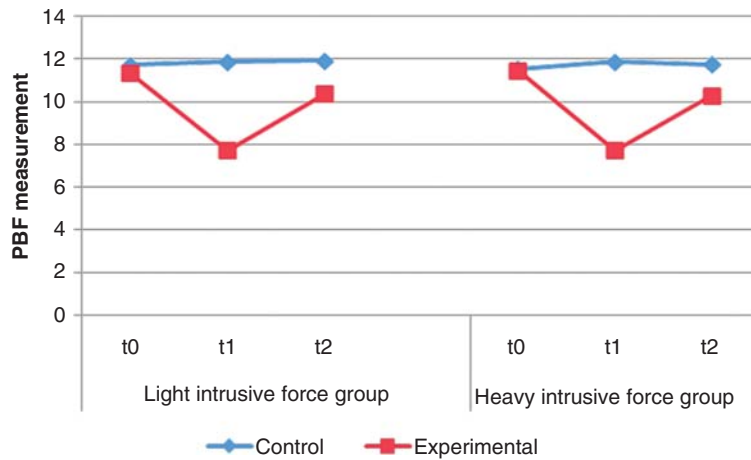


Figure 2. PBF measurements during the observation periods and comparisons of session-related variances.

of the experimental groups, no absence of PBF was recorded at any time and PBF values at 3 weeks did not differ significantly from baseline levels for either of the experimental groups.

The findings that orthodontic intrusion can have particularly detrimental effects on PBF during the initial intrusion period are supported by the results of a previous study that found PBF values to decrease by 80% during the first minutes of orthodontic intrusion [11]. Several other studies have also reported an obvious reduction in PBF and marked histological changes in pulp as a result of intrusive force [6,12–15], although, in line with the findings of the present study, PBF was found to gradually recover from the temporary reduction resulting from intrusive force. Ikawa et al. [16] described how intrusive force significantly reduced PBF and Sano et al. [6] revealed that PBF was significantly reduced during the continuous application of intrusive force, but that recovery occurred after wire removal. In the latter study, brief intrusive force also produced a significant reduction in PBF and no differences in the rate of reduction were observed at different observation periods [6].

Brodin et al. [11] also showed that orthodontic intrusion evoked a temporary reduction in PBF, whereas extrusion had no effect. A histological study of rat pulp tissue by Grunheid et al. [17] showed that various pathological signs peaked from 24–72 h after force application, but returned to their initial values after 168 h. Another histological study by Stenvik and Mjör [13] reported odontoblastic degeneration and vacuolization due to intrusive force as well as stasis in pulp vessels, as determined by the presence of brown pigment from deteriorating erythrocytes following application of intrusive forces greater than 150–200 g. In contrast to these findings, Barwick and Ramsay [9] indicated that PBF does not change during the brief application of intrusive force. Although their study found that the reduction in PBF as a result of the application of an intrusive forces ranging from 75–4498 g for 4 min was not statistically significant, the authors suggested that this could be attributed in part to the small sample size ($n = 8$) and/or LDF signal error.

Blood flow in human maxillary dental pulp following exposure to light or heavy intrusive force by mini-

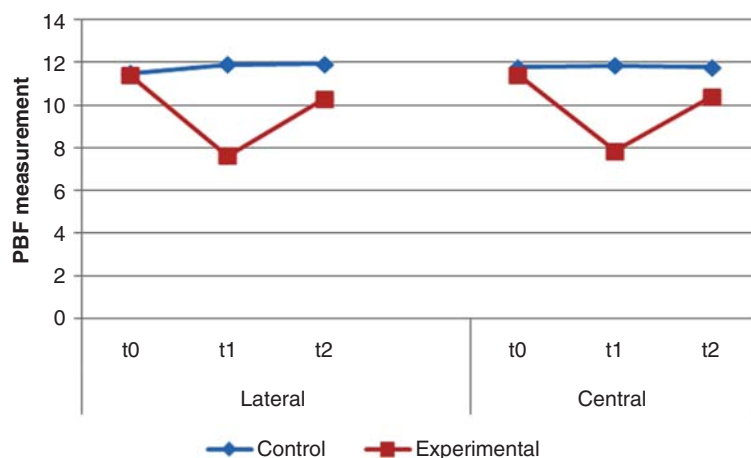


Figure 3. PBF measurements during the observation periods and comparisons of force-related variances.

implants has rarely been assessed. By measuring PBF in human dental pulp after exposure to 40 g or 120 g of intrusive force from mini-implants at 3 days and 3 weeks, this clinical study aimed to compare early and late responses. Moreover, measuring PBF at 3 days made it possible to observe gradual signs of inflammation due to light force [10,18], whereas measurements taken at 3 weeks were designed to capture possible chronic changes [10,18]. Proffit et al. [19] considered a range of 10–20 g to be the optimum magnitude of force for intrusion, whereas Woodside et al. [20] considered 50–100 g to represent light force and Stenvik and Mjor [13] observed intravascular and extravascular degradation of red blood cells with forces above 120 g. In view of these earlier reports, this study chose to examine intrusion forces of 40 g and 120 g. Our study found no direct relationship between magnitude of force and pulpal changes. This conflicts with findings of previous studies that found the nature and magnitude of force to have an effect on PBF values [19,20].

PBF is known to decrease with age and histological findings have shown that not only do the number of blood vessels decrease with age, the pulpal area also decreases with age due to increases in calcified tissue [21,22]. In the present study, in order to eliminate the effects of age, all subjects were in the same age group (age 18–25 years). Moreover, the initial periapical radiographs were taken to eliminate the occurrence risk of pulp stones in a young population. Tooth type has also been suggested as a factor in PBF response to intrusive force [16]. Given that the mesiodistal width of upper central incisors is greater at the incisal edge than at the cemento-enamel junction, it is possible that tooth intrusion would compress the adjacent gingiva and periodontal ligament, thereby reducing the signal from these tissues [16]. However, the present study found no significant differences in PBF changes in central and lateral incisors due to intrusion.

Results showed successful incisor intrusion and excellent stability of mini-implants after immediate loading with forces of 40–120 g and 100% of the mini-implants remained stable throughout the 3-week experimental period. This success rate may be attributed to the initial stability of the mini-implants, minimal peri-implant inflammation, a soft diet and controlled experimental situation. Mini-implants tend to cause less pain and discomfort to patients, since they are placed without an incision or flap surgery [8]. Conventional prosthetic implants have a limited range of application because of their relatively large size. The mini-implant used in this study is only 1.3 mm in diameter and 5 mm in length. Accordingly, it is easily inserted between the central and lateral incisor roots and oral hygiene is easy to maintain; thus, the implant is able to bear the load of a continuous intrusive force without causing inflammation.

Critique of LDF

Currently, the tests most commonly used to obtain information about the condition of the pulp are mainly thermal and electric pulp tests [23]. However, these methods have limitations in providing an accurate diagnosis, because they subjectively imply vitality through sensory responses from the patient, leading to inconclusive results. Furthermore, sensitivity tests are perceived as unpleasant and occasionally painful stimuli. A major limitation associated with conventional pulp testing methods is that they indirectly monitor pulp vitality by measuring a neural response, not vascular circulation [23]. Vascular supply and not innervation is the most accurate determinant of pulp vitality [24]. As a result, teeth that have temporarily or permanently lost their sensory function may be non-responsive to these tests. False results are possible in teeth with healthy pulps undergoing orthodontic treatment [25] because the pulp's sensory elements may be disturbed for up to 9 months. In this connection, LDF was chosen for this study.

In contrast to a previous study reporting greater decreases in PBF after intrusion with heavy as compared to light force [6], the present study found that mean PBF following intrusion did not vary significantly according to the amount of intrusive force applied. This finding may be a result of the relatively light forces applied to both experimental groups in this study and/or sensitivity limitations of the laser Doppler flowmeter. LDF assessment of PBF is highly susceptible to environmental and technical factors. Variables such as flowmeter characteristics [26,27], gingival isolation device [28,29], ambient temperature, position of the probe and patient position and rest status [26,28,30,31] as well as other patient-related factors such as stress, medication and age-related changes may significantly influence LDF results [32–35]. Although lasers with longer wavelengths give higher Flux readings, probably due to their greater penetration through tooth tissue, non-pulpal blood flow may be included within the signal, thereby reducing the vital-to-non-vital signal ratio [27,36]; for this reason, this study used a 632.8 nm laser source rather than a 780 nm or 810 nm laser. In order to stabilize the probe, maintain it in contact with the tooth and create a reproducible position for follow-up measurements, the present study used a custom-made acrylic-resin splint. In conjunction with the splint, cotton rolls were applied between the lip and teeth in order to minimize the contribution of neighboring pulp and gingiva to the Flux signal, since a rubber-dam could not be applied to teeth with brackets [28]. A similar technique has been successfully employed in earlier studies [37]. In order to improve the validity of measurements, special care was also taken to maintain ambient temperatures and patient-related factors such as position, rest and stress levels. For eliminating these disadvantages, a recent concept is that application of orthodontic forces may

induce expression of sensory neuropeptides and some cytokines followed by alteration of pulpal blood flow [7]. These data open up new avenues for future research to evaluate the biological aspects of dental pulp tissue changes incident to orthodontic tooth movement.

Conclusion

This study demonstrated the effects of short- and long-term incisor intrusion with mini-implants using different magnitudes of force on blood flow in pulpal tissue. Based on the findings of this study, the following conclusions were drawn:

- (1) PBF values decrease in pulp of teeth subjected to 3 days of either light (40 g) or heavy (120 g) orthodontic intrusion.
- (2) PBF values tend to return to their initial levels after 3 weeks of either light (40 g) or heavy (120 g) intrusion.
- (3) PBF values are significantly lower at 3 days of intrusion when compared to 3 weeks of intrusion.
- (4) Changes in PBF as a result of intrusion do not vary significantly by tooth type (between central and lateral incisors).
- (5) Changes in PBF observed at different lengths (3 days, 3 weeks) of exposure to intrusive force are not significantly affected by the amount of force (40 g or 120 g) applied.
- (6) The lack of significant differences in PBF observed between teeth exposed to light and heavy force is most probably due to the relatively light forces applied in this study.

Although incisor intrusion with mini-implants caused slight regressive changes in pulp tissue over the short-term, blood flow was maintained in the dental pulp, indicating that blood vessel functioning was maintained and the regressive changes observed in pulp tissue improved after 3 weeks of intrusion. These results indicate that changes in pulpal blood flow after radical intrusion with mini-implants are reversible.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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