Original Article

The effect of clear aligner and fixed orthodontic treatment on the development of pulp stones: a retrospective observational study

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ABSTRACT

Objectives: To report the prevalence of pulp stones (PSs) in molars of orthodontically treated patients, investigate the impact of orthodontic treatment (ORT) using clear aligners (CAs) and fixed appliances (FAs) on the development of PSs in molars, and investigate the association between the incidence of PSs during ORT and the studied variables.

Materials and Methods: Pretreatment orthopantomograms (OPGs) of 600 patients were assessed. Of those, posttreatment OPGs of 272 patients were available. Molars were subdivided into four subgroups based on type of appliance and force application: group 1, first molars included in FA (n = 707); group 2, first molars included in CA (n = 157); group 3, second molars included in CA (n = 189); group 4, second molars not included in FA during treatment (n = 880). PSs were diagnosed when radiopaque bodies were detected in the coronal and/or radicular pulp space. PS changes after treatment were recorded and analyzed using SPSS.

Results: The prevalence of PSs was 16.6%. The overall incidence of PSs increased by 5.9% and 4.5% in groups 1 and 2, and by 3.7% and 5.3% in groups 3 and 4, respectively ($P \leq .05$). No significant differences were found between appliance type groups (1 and 2) and force application groups (3 and 4). The association between PS development and the type of appliance or treatment duration was not significant.

Conclusions: The incidence of PSs increased during ORT, which was more pronounced in maxillary molars. PS development during ORT was not associated with orthodontic appliance type, force application, and duration of ORT. (*Angle Orthod*. 0000;00:000–000.)

KEY WORDS: Orthodontic treatment; Dental pulp stone; Pulp reaction; Panoramic radiographs

INTRODUCTION

Pulp stones (PSs) are calcified structures with calcium-phosphorus ratios comparable with dentin. Histologically, they usually consist of concentric layers of mineralized tissue formed by surface accretion around blood thrombi, dying or dead cells, or collagen fibers. They can develop discretely or diffusely in the pulpal tissue of teeth.[1]

PSs range in size from a microscopic particle to a large mass that completely fills the pulp chamber.[2] They appear as radiopaque structures within the coronal and/or the radicular pulp, and their radiographic appearance can vary. Some PSs occupy most of the pulp chamber and can be either round or oval, whereas others could have a diameter of 2 mm or 3 mm. On radiographs, only these significant calcified masses can be identified.[3] PSs can be developed in any tooth type, and they frequently get bigger with age.[4,5]

Several factors have been implicated in causing pulp calcifications, including systemic diseases, persistent irritation, genetics, and trauma.[2,5–7] Orthodontic tooth movement has been linked to adverse effects that affect the dental pulp,[8,9] in a way similar to stimulation brought on by trauma.[7,10] According to several studies,[5,11,12] the force applied during orthodontic

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treatment (ORT) may affect the pulp by causing pulpal tissue destruction through the formation of secondary dentin, changes in pulpal flow rate, internal root resorption, pulpal necrosis, cyst formation, and pulpal calcifications.[5,7–9] The prevalence of long-term dental pulp injury resulting from ORT varies greatly among adolescents receiving ORT, ranging from 2% to 17% for root canal obliteration and from 1% to 14% for pulpal necrosis.[13]

The calcification phenomenon in the tooth pulp is a subject of ongoing interest both because PSs are distinct dental entities and they have a therapeutic implication. The therapeutic implication is more critical since they can make access to the root canal system during endodontic therapy difficult or even impossible, and they may also result in unnecessary tooth extraction.[14]

Uncertainties still exist about the effect of orthodontic therapy on PS formation. Authors of several studies have investigated the development of PSs following fixed ORT using either radiographs or histological sections.[5,11,12,15,16] These authors showed inconsistent results regarding the correlation between orthodontic force (ORF) and PS development. Stenvik and Mjör (1970) observed PS formation due to intrusive force using a fixed appliance (FA),[17] while authors of another study found no link between PS formation and ORF regardless of the type of orthodontic movement.[18] No previous authors have examined the potential relationship between the type of orthodontic appliance, clear aligners (CAs) vs FAs, and the formation of PSs. The primary aim of this study was to investigate the impact of ORT using CAs and FAs on the development of PSs in molar teeth.

The secondary aims were to

- report on the prevalence of PSs in the molars of orthodontically treated patients, and
- investigate the association between PS development after ORT and age, gender, facial side, type of malocclusion, type of orthodontic appliance, and ORT duration.

The null hypothesis is that no significant difference would be found in the incidence of PS development after ORT between FA and CA ORT groups.

MATERIALS AND METHODS

This retrospective observational study is described according to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for the presentation of cohort studies.[19] A convenience sample comprising pretreatment orthopantomograms (OPGs) of 600 orthodontic patients was included. Of those, posttreatment images of 272 patients were available to assess the impact of ORT on PS development. Approval for the present study was obtained from the Jordan University of Science and Technology (JUST) ethical committee (reference 29/28/2016).

Prevalence of PSs in Molar Teeth

Pretreatment OPGs of 600 orthodontic patients (317 females and 283 males; mean age 20.81 $\pm$ 6.29 years) taken for diagnosis at the Orthodontic Teaching Clinics/JUST, Irbid, Jordan, and as a pretreatment record at AlSunna Orthodontic Center/Amman, Jordan, between the years 2017 and 2022 were included after fulfilling the following inclusion criteria: age of at least 14 years, no history of previous ORT, intact molar teeth with no periapical lesions, and healthy periodontium. Restored, carious or endodontically treated teeth, patients with syndromes or systemic diseases, and poor-quality panoramic radiographs which could interfere with PS recording were excluded from the study.

Effect of ORT and the Type of Orthodontic Appliance on the Development of PSs

A total of 1933 maxillary and mandibular first and second molars from pretreatment and posttreatment OPG images of 272 patients (123 males and 149 females) were available. The age of the patients when commencing ORT was between 14 and 36 years old with a mean age of 19.28 $\pm$ 4.27 years. ORT was performed without extraction using either FAs or CAs at JUST/Irbid, Jordan, and AlSunna Orthodontic Center/Amman, Jordan. The posttreatment OPGs were taken immediately after treatment with the mean duration of ORT being 19.03 $\pm$ 4.65 months. Posttreatment OPGs were taken to assess periodontal health after ORT.

The included molars were subdivided into four subgroups:

- Group 1: First molars included in FA (n $=$ 707),
- Group 2: First molars included in CA (n $=$ 157),
- Group 3: Second molars included in CA (n $=$ 189), and
- Group 4: Second molars not included in FA (n $=$ 880).

Therefore, the change in PS status in groups 1–3 was considered an impact of ORT.

Although the panoramic radiographs were taken in two different dental clinics, the same machines were used (Orthoslice-1000C, Marne La Vallee Cedex-2, France) with the following exposure parameters: 64 KVp, 16 Ma, and 0.64 seconds exposure, using a standardized technique with the teeth in light intercuspation.

Radiograph assessment was performed by one oral and maxillofacial radiologist and one endodontist with more than 15 years of experience. Assessment was accomplished under the same conditions for the teeth

Table 1. Pretreatment Prevalence of PSs in Maxillary and Mandibular First and Second Molars in Orthodontic Patients (n = 600)[a]

	Absence	Presence	Total	Test Statistic	*P* Value
First molars					
Maxillary first molars	740 (70%)	318 (30%)	1058	42.432	< .001*
Mandibular first molars	827 (82%)	183 (18%)	1010		
Total	1567 (75.8%)	501 (24.2%)	2068		
Second molars					
Maxillary second molars	1044 (88%)	145 (12%)	1189	19.006	< .001*
Mandibular second molars	1086 (93%)	89 (7%)	1175		
Total	2130 (90%)	234 (10%)	2364		
Total teeth (first and second molars)	3697 (83.4)	735 (16.6)	4432		

[a] PS indicates pulp stone; * *P* significant at $P < .001$.

examined. Definitive PS diagnosis was considered when definite radiopaque bodies as dental PSs were noted in the coronal and/or the radicular pulp space.

Interexaminer and intraexaminer reliability was done for 20% of the sample with a 3-week interval between the first and second assessments. The evaluators assessed the radiographs individually, and when PSs were present, the final diagnosis was made by both evaluators. If any conflict occurred, it was solved by consensus. Additionally, age, gender, type of malocclusion, type of treatment (FA or CA), and duration of treatment were registered.

Statistical Analysis

Statistical analyses were performed using SPSS version 28 (SPSS, Chicago, IL) to IBM Corp., Armonk, N.Y., USA. Within-subject and between-subjects differences were detected using the nonparametric McNemar and χ^2 tests, respectively. Associations between the studied variables and the development of PSs were analyzed using Pearson χ^2 test and logistic regression analyses. The level of significance was set at $P \leq .05$.

RESULTS

The results of κ coefficients for both interexaminer and intraexaminer reliability were excellent, with ranges of 0.82–1.00 and 0.89–1.00, respectively.

Prevalence of PSs in Molar Teeth

A total of 4432 maxillary and mandibular first (2068) and second molars (2364) from 600 panoramic radiographs was assessed and analyzed. PSs were detected in 16.6% of the included molars (24% and 10% of first and second molars, respectively; Table 1).

A significant association was found between prevalence of PSs and malocclusion, age, tooth type, and dental arch type ($P < .001$; Tables 2 and 3). The results of the binary logistic regression showed that, compared with Class III malocclusion, the odds of having PSs decreased by 2.4% ($P = .038$) and by 5.5% ($P < .001$)

Table 2. Association Between Prevalence of PSs and Malocclusion, Gender, Age, Facial Side, Dental Arch, and Molar Type[a]

	Absence	Presence	Total Sample	χ^2 Value	*P* Value
Malocclusion					
Class I molars	1632 (80%)	408 (20%)	3687	21.92	< .001*
Class II molars	1036 (85.8%)	172 (14.2%)			
Class III molars	341 (77.7%)	98 (22.3%)			
Gender					
Females	1947 (83.8%)	376 (16.2%)	4432	0.559	.467
Males	1750 (83%)	359 (17%)			
Age					
< 18 y (adolescents)	1357 (92.7%)	107 (7.3%)	4432	135.952	< .001*
≥18 y	2340 (78.8%)	628 (21.2%)			
Facial side					
Right	1860 (83 > 6%)	364 (16.4%)	4432	0.152	.716
Left	1837 (83.2%)	371 (16.8%)			
Dental arches					
Maxilla	1784 (79.4%)	463 (20.6%)	4432	53.278	< .001*
Mandibular	1913 (87.6%)	272 (12.4%)			
Molar type (first vs second molars)					
First molars	1567 (75.8%)	501 (24.2%)	4432	163.69	< .001*
Second molars	2130 (90.1%)	234 (9.9%)			

[a] PS indicates pulp stone; * *P* significant at $P < .001$.

Table 3. Variables in the Equation[a]

Step 1[a]	B	SE	Wald	df	Significance	Exp(B) (95% CI)
Malocclusion			35.953	2	.000	
Malocclusion(1)	−0.281	0.136	4.288	1	.038	0.755 (0.578, 0.985)
Malocclusion(2)	−0.806	0.151	28.409	1	.000	0.447 (0.332, 0.601)
Gender(1)	−0.040	0.090	0.192	1	.661	0.961 (0.805, 1.147)
@agecode(1)	−1.437	0.119	144.963	1	.000	0.238 (0.188, 0.300)
@sidecode(1)	−0.199	0.091	4.756	1	.029	0.820 (0.685, 0.980)
First_second(1)	1.054	0.095	123.190	1	.000	2.868 (2.381, 3.454)
JAWcode(1)	0.573	0.093	37.882	1	.000	1.773 (1.478, 2.128)
Constant	−1.542	0.163	89.700	1	.000	0.214

[a] SE indicates standard error; CI, confidence interval; Variable(s) entered on step 1: Malocclusion, Gender, @agecode, @sidecode, First_second, JAWcode.

in Class I and II malocclusions, respectively. Regarding molar type, the odds of developing PSs were 2.9 times greater in first molars than second molars and 1.7 times more likely to develop in the maxilla than the mandible ($P < .001$). Additionally, the odds of developing PSs increased with age ($P < .001$).

Impact of ORT on the Development of PSs in the Molars

Within-Group Differences. FA treatment group: The incidences of PS development in group 1 (first molars, FA) were 8.2% ($P < .001$) and 3.5% ($P < .001$) in the maxilla and mandible, respectively (Table 4).

CA groups: The incidences of PS development in group 2 (first molars, CA) were 7.8% ($P < .031$) and 1.3% ($P > .05$) in the maxilla and mandible, respectively. In group 3 (second molars, CA), the incidences of PS development were 4.2% ($P > .05$) and 3.2% ($P > .05$) in the maxilla and mandible, respectively (Table 4).

Molars not subjected to ORT: The incidences of PS development in group 4 (second molars not included in FA) were 6.5% ($P < .001$) and 4.1% ($P < .001$) in the maxilla and mandible, respectively (Table 4).

Between-Groups Differences. No significant differences were detected in the incidence of PSs in the first molars between FA and CA, either in the maxilla or the mandible (groups 1 and 2). Additionally, when group 3 was compared with group 4, no statistically significant differences were detected in either the maxilla or the mandible (Table 4).

Table 4. Frequency of PS Pre-ORT and Post-ORT According to Tooth Type, Incidence of PSs During ORT, and the Difference Between Pretreatment and Posttreatment Formation of PSs Using McNemar Test[a]

		Pre-ORT		Post-ORT			Within-Group (Pre-Post)	
	No. teeth	Absence	Presence	Absence	Presence	Incidence of PS Development	McNemar Test Statistics	*P* Value
Maxilla								
Group 1 First molar (FA)	367	287 (78.2%)	80 (21.8%)	257 (70.0%)	110 (30.0%)	30 (8.2%)	28.033	<.001***
Group 2 First molar (CA)	77	59 (76.6%)	18 (23.4%)	53 (68.8%)	24 (31.2%)	6 (7.8%)	4.167	.031*
Between-groups differences		(χ^2 = 0.092, *P* = .761)		(χ^2 = 0.043, *P* = .835)		(χ^2 = 0.012, *P* = .911)		
Group 3 Second molar (CA)	95	84 (88.4%)	11 (11.6%)	80 (84.2%)	15 (15.8%)	4 (4.2%)	2.250	.134
Group 4 Second molar (FA)	446	417 (93.5%)	29 (6.5%)	388 (87.0%)	58 (13.0%)	29 (6.5%)	27.034	<.001***
Between-groups differences		(χ^2 = 2.948, *P* = .086)		(χ^2 = 0.520, *P* = .471)		(χ^2 = 0.718, *P* = .397)		
Total first molars	444	346 (77.9%)	98 (22.1%)	310 (69.8%)	134 (30.2%)	36 (8.1%)	34.028	<.001***
Mandible								
Group 1 first molar (FA)	340	300 (88.2%)	40 (11.8%)	288 (84.7%)	52 (15.3%)	12 (3.5%)	10.083	<.001***
Group 2 first molar (CA)	80	65 (81.3%)	15 (18.8%)	64 (80.0%)	16 (20.0%)	1 (1.3%)	0.000	1.000
Between-groups differences		(χ^2 = 2.777, *P* = .096)		(χ^2 = 1.057, *P* = .304)		(χ^2 = 1.122, *P* = .290)		
Group 3 second molar (CA)	94	89 (94.7%)	5 (5.3%)	86 (91.5%)	8 (8.5%)	3 (3.2%)	1.333	.250
Group 4 second molar (FA)	434	418 (96.3%)	16 (3.7%)	400 (92.2%)	34 (7.8%)	18 (4.1%)	16.056	<.001***
Between-groups differences		(χ^2 = 0.539, *P* = .463)		(χ^2 = 0.048, *P* = .826)		(χ^2 = 0.185, *P* = .667)		
Total first molars	420	365 (86.9%)	55 (13.1%)	352 (83.8%)	68 (16.2%)	13 (3.1%)	11.077	<.001***
Total maxillary and mandibular molars								
Group 1 first molar (FA)	707	587 (83.0%)	120 (17.0%)	545 (77.1%)	162 (22.9%)	42 (5.9%)	40.024	<.001***
Group 2 first molar (CA)	157	124 (79.0%)	33 (21.0%)	117 (74.5%)	40 (25.5%)	7 (4.5%)	5.143	.016*
Between-groups differences		(χ^2 = 1.443, *P* = .230)		(χ^2 = 0.471, *P* = .492)		(χ^2 = 0.527, *P* = .468)		
Group 3 second molar (CA)	189	173 (91.5%)	16 (8.5%)	166 (87.8%)	23 (12.2%)	7 (3.7%)	5.143	.016*
Group 4 second molar (FA)	880	835 (94.9%)	45 (5.1%)	788 (89.5%)	92 (10.5%)	47 (5.3%)	45.021	<.001***
Between-groups differences		(χ^2 = 3.249, *P* = .071)		(χ^2 = 0.477, *P* = .490)		(χ^2 = 0.869, *P* = .351)		
Total first molars	864	711 (82.3%)	153 (17.7%)	662 (76.6%)	202 (23.4%)	49 (5.7%)	47.020	<.001***

[a] PS indicates pulp stone; ORT, orthodontic treatment; CA, clear aligner; and FA, fixed appliance; * Significant at $P < .05$, ** Significant at $P < .01$, *** Statistically significant at $P < .001$.

Table 5. Frequency of PS Pre-ORT and Post-ORT, and Change in PSs Based on the Studied Variables[a]

	No. teeth	Pre-ORT Absence	Pre-ORT Presence	Post-ORT Absence	Post-ORT Presence	Change in PS Development	Pearson χ^2	*P* Value
Gender								
Female	477	392 (82.2%)	85 (17.8%)	367 (76.9%)	110 (23.1%)	25 (5.2%)	0.368	.544
Male	387	319 (82.4%)	68 (17.6%)	295 (76.2%)	92 (23.8%)	24 (6.2%)		
Total	864	(χ^2 = 0.009, *P* = .924)		(χ^2 = 0.060, *P* = .806)				
Age								
<18 y	462	391 (84.6%)	71 (15.4%)	363 (78.6%)	99 (21.4%)	28 (6.1%)	0.281	.596
≥18 y	402	320 (79.6%)	82 (20.4%)	299 (74.4%)	103 (25.6%)	21 (5.2%)		
	864	(χ^2 = 3.732, *P* = .033)*		(χ^2 = 2.110, *P* = .146)				
Dental arches								
Maxillary molars	444	346 (77.9%)	98 (22.1%)	310 (69.8%)	134 (30.2%)	39 (7.3%)	9.074	.002**
Mandibular molars	420	365 (86.9%)	55 (13.1%)	352 (83.6%)	68 (16.2%)	16 (3.1%)		
	864	(χ^2 = 11.935, *P* < .001)***		(χ^2 = 23.581, *P* < .001)***				
Facial sides								
Right side	432	358 (82.9%)	74 (17.1%)	337 (78.0%)	95 (22.0%)	21 (4.9%)	1.060	.303
Left side	432	353 (81.7%)	79 (18.3%)	325 (75.2%)	107 (34.8%)	28 (6.5%)		
	864	(χ^2 = 0.199, *P* = .656)		(χ^2 = 0.930, *P* = .335)				
Malocclusions								
Class I malocclusion	358	286 (79.9%)	72 (20.1%)	267 (74.6%)	91 (25.4%)	19 (5.3%)	0.706	.703
Class II malocclusion	473	403 (85.2%)	70 (14.8%)	374 (79.1%)	99 (20.9%)	29 (6.1%)		
Class III malocclusion	33	22 (66.7%)	11 (33.3%)	21 (63.6%)	12 (36.4%)	1 (3.0%)		
	864	(χ^2 = 9.695, *P* < .008)**		(χ^2 = 5.521, *P* = .063)				
Types of ORT								
Fixed orthodontic	707	587 (83%)	120 (17.0%)	545 (77.1%)	162 (22.9%)	42 (5.9%)	0.527	.468
Clear aligners	157	124 (79.0%)	33 (14.4%)	117 (74.5%)	40 (25.5%)	7 (4.5%)		
		(χ^2 = 1.443, *P* = .230)		(χ^2 = 0.471, *P* = .492)				
Duration of ORT								
Up to 1 y	51	39 (76.5%)	12 (23.5%)	36 (70.6%)	15 (29.4%)	3 (5.9%)	0.463	.794
13–24 mo (2 y)	699	575 (82.3%)	124 (17.7%)	637 (81.1%)	162 (23.2%)	38 (5.4%)		
>2 y	114	97 (85.1%)	17 (14.9%)	89 (78.1%)	25 (21.9%)	8 (7.0%)		
		(χ^2 = 1.798, *P* = .407)		(χ^2 = 1.186, *P* = .553)				

[a] PS indicates pulp stone; ORT, orthodontic treatment; * Significant at *P* < 0.05, ** Significant at *P* < .01, *** Significant at *P* < .001.

Table 5 shows that maxillary first molars experienced a higher incidence of PS development following ORT than mandibular first molars (PSs increased by 7% in maxillary and 3% in mandibular molars; *P* = .002). This finding was confirmed using multinomial logistic regression (Table 6), in which the odds of developing PSs during ORT were two times higher in the upper arch than the lower arch (*P* < .001). Additionally, no significant association was detected between PS development during ORT and the type of orthodontic appliance or the duration of treatment.

DISCUSSION

Identifying PSs is crucial for successful endodontic outcomes, helping endodontists to be well prepared to modify their techniques for their removal. Although the association between orthodontic tooth movement and PS development has been investigated previously, reported findings were contradictory.[5,11,12,15] In addition, the relationship between PS development and orthodontic appliance type and malocclusion has not been investigated before.

Radiographs or histological sections have been employed to study the presence of PSs.[7,18,20,21] In

Table 6. Multinomial Regression Analysis of the Association Between Studied Variables and Incidence of PS Development During ORT[a]

Variables Interaction	B	SE	Wald	df	Significance	Exp(B) (95% CI)
PS development during ORT						
Molar type	0.499	0.571	0.764	1	.382	1.648 (0.538, 5.048)
Dental arch	0.740	0.217	11.596	1	.001*	2.096 (1.369, 3.209)
Age	−0.105	0.214	0.240	1	.624	0.901 (0.592, 1.370)
Gender	−0.038	0.208	0.034	1	.854	0.962 (0.640, 1.448)
Treatment type	0.153	0.435	0.124	1	.724	1.166 (0.497, 2.734)
ORF	−0.221	0.610	0.131	1	.717	0.802 (0.242, 2.652)
Malocclusion type	−0.227	0.192	1.401	1	.237	0.797 (0.547, 1.161)
Treatment duration	0.244	0.255	0.912	1	.340	1.276 (0.774, 2.105)

[a] PS indicates pulp stone; ORT, orthodontic treatment; ORF, orthodontic force; CA, clear aligner; FA, fixed appliance; SE, standard error; and CI, confidence interval; PS development (0 = no PS developed, 1 = PS developed, 3 = PS already present pretreatment), molar type (1 = first molars, 2 = second molars), dental arch (1 = upper, 2 = lower), age (1 ≤18 y, 2 ≥18 y), gender (1 = females, 2 = males), treatment type (1 = CA, 2 = FA), ORF (1 = subjected to ORF, 2 = no ORF), malocclusion (1 = Class I, 2 = Class II, 3 = Class III), treatment duration (1 = up to 1 y, 2 = 12–24 mo, 3 ≥2 y); *Significant at P > .001.

orthodontic practice, panoramic radiographs are taken routinely as the primary diagnostic tool.[22] Therefore, panoramic radiographs can be considered a screening tool for detecting PSs due to their availability, affordability, and cost effectiveness.[3,23] Authors of some studies used periapical and bitewing radiographs for PS diagnosis. However, visualization of PSs may be hampered by overlap with the alveolar bone. Additionally, multiple radiographs must be performed for the maxillary and mandibular teeth and cannot be applied regularly for screening purposes.[24] Cone-beam computed tomography is a reliable approach for detecting PSs.[25] However, the accompanying expenses and high radiation are significant drawbacks that limit its usage.[26]

Incidence of PSs in this study was 16.6%, which was consistent with some previous studies[27–29] and in disagreement with others in which authors reported a higher incidence rate.[25,30] The difference in the reported incidence of PSs may be due to differences in the sample size, race or population, and methodology (type of radiographic images). Differences in how the incidence of PSs was reported existed, with some authors reporting incidence based on both person and tooth counts,[15,21] while others reported incidence based only on tooth counts.[5,12,20]

In the current study, maxillary and mandibular first molars developed PSs significantly following ORT. The PS change in the mandibular first molars was comparable with previous studies, in which authors reported up to 4% change following ORT,[5,11,15] while the maxillary first molars showed a higher increase in PS development compared with previous studies. To the contrary, Sarang et al.[31] found no significant increase in PS development post-ORT. The higher rate of PS development in the maxilla could be explained by its lower bone density, resulting in greater tooth displacement than in the mandible.[32,33] As bone density decreases, the rate of tooth movement increases. In contrast, mandibular molars are located within a denser alveolar process, providing greater anchorage and resistance to tooth movement than maxillary molars.[33] Also, during ORT, more uncontrolled tipping in the maxilla may exist than in the mandible.[33] As a result, the duration of inflammatory reactions and the occurrence of greater forces on maxillary teeth tend to provoke more pulp calcification.[17]

When comparing overall PS development after ORT, no difference was observed. As second molars in group 4 were not included in the appliance, this excluded any association of ORT with the development of PSs. This finding contradicted Afsari et al.,[20] who compared orthodontic patients and a control group for the formation of PSs and reported a significant link between PS formation and ORT.

In the present study, gender differences in the incidence of PSs following ORT were not detected. This disagreed with Afsari et al.,[20] who concluded that a significant link existed between gender and PS formation after ORT, and agreed with others.[15,21,34]

In the current study, the incidence of PS formation increased with age with no correlation between age and the likelihood of developing PSs after ORT. This disagreed with Ertas et al.,[5] who found that PS development after ORT increased with age. This may be explained by the gradual reduction of pulp cells and increase of fibrous materials causing calcification[4] as people age.

The findings of the current study indicated that PS prevalence following ORT was similar on both the right and left sides of the mouth, which was consistent with previous reports.[5,12,15,35] Also, malocclusion types were not associated with PS formation after ORT, which was consistent with the findings of Kublitski et al.[35]

In the current study, both CAs and FAs showed similar outcomes for the development of PSs after ORT. Authors of previous studies reported a significant increase in PSs following fixed ORT.[5,11,12,15] In a recent systematic review, rapid maxillary expansion resulted in pulp calcification.[34] None of the participants in the present study were treated by rapid maxillary expansion appliances. Comparison with other studies is not possible since we are the first to investigate PS development after CA.

In the present study, no correlation was found between the duration of ORT and PS development. This finding was like what was found in some studies,[20,35] and it disagreed with others.[15,21]

Based on the results of the current study, the null hypothesis could not be rejected. However, the outcomes should be interpreted with caution due to the small sample size, unequal number of CA and FA participants, and lack of a control group.

CONCLUSIONS

- The incidence of PSs increased during ORT and was more pronounced in maxillary than mandibular molars.
- PS development during ORT was not associated with appliance type, force application, or duration of ORT.
- Pretreatment prevalence of PSs was 16.6% and was associated with age, molar type, dental arch, and malocclusion type.
- The results of this study cannot be generalized due to selection bias since a single operator treated the participants in a single center.

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