

CHAPTER IV

RESULTS

The results were divided into two parts.

I. Occurrence

II. Factors associated with external apical root resorption

I. Occurrence

There were 564 teeth from 181 cases that were consistent with the criteria for sample selection. There was a normal distribution of data for EARR among the 564 teeth as illustrated in histograms (Figures 4.1 and 4.2).

Number of teeth

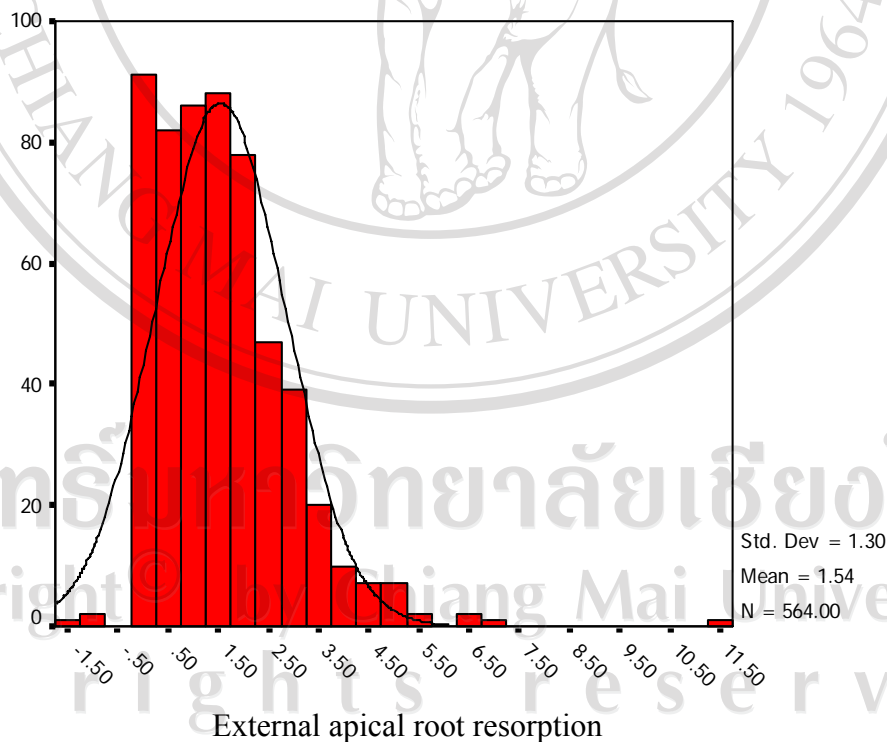


Figure 4.1 Histogram showing EARR in 564 teeth

Number of teeth

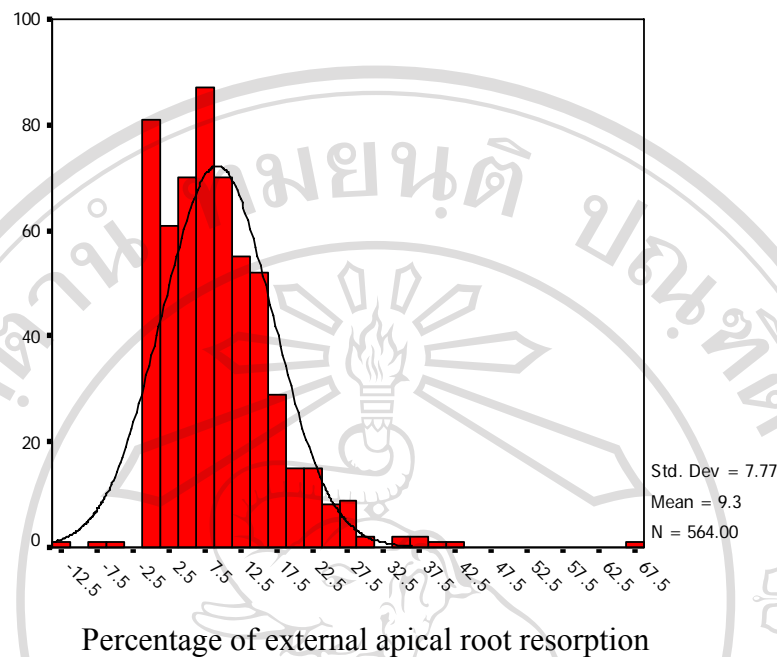


Figure 4.2 Histogram showing percentage of EARR in 564 teeth

The results showed that the mean amount of EARR of in maxillary incisors was 1.55 ± 1.30 mm or $9.32 \pm 7.78\%$ of the root length. The average amounts of EARR in each maxillary incisor were 1.41 ± 1.23 , 1.62 ± 1.26 , 1.37 ± 1.43 and 1.76 ± 1.28 mm in right central and lateral, left central and lateral incisor, respectively. The percentages of EARR per tooth were 8.24 ± 7.10 , 9.63 ± 7.80 , 8.24 ± 8.54 and 10.93 ± 7.57 , respectively (Table 4.1, Figures 4.3 and 4.4).

Table 4.1 Mean EARR (mm) and mean percentage of EARR per tooth in each maxillary incisor

Tooth	n	Mean root length \pm SD	Mean EARR \pm SD (mm)	Mean percentage of EARR per tooth \pm SD (%)
11	150	16.42 ± 2.11	1.41 ± 1.23	8.24 ± 7.10
12	131	16.14 ± 2.10	1.62 ± 1.26	9.63 ± 7.80
21	149	16.52 ± 2.04	1.37 ± 1.43	8.24 ± 8.54
22	134	16.24 ± 2.14	1.76 ± 1.28	10.93 ± 7.57

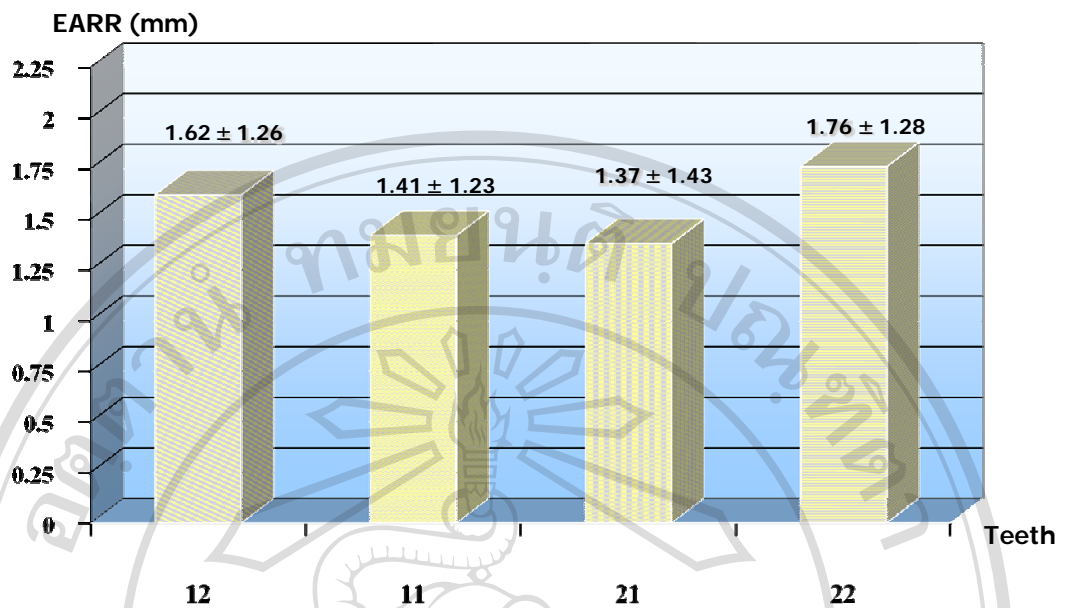


Figure 4.3 Mean EARR (mm) in each maxillary incisor (11, 12, 21, 22)

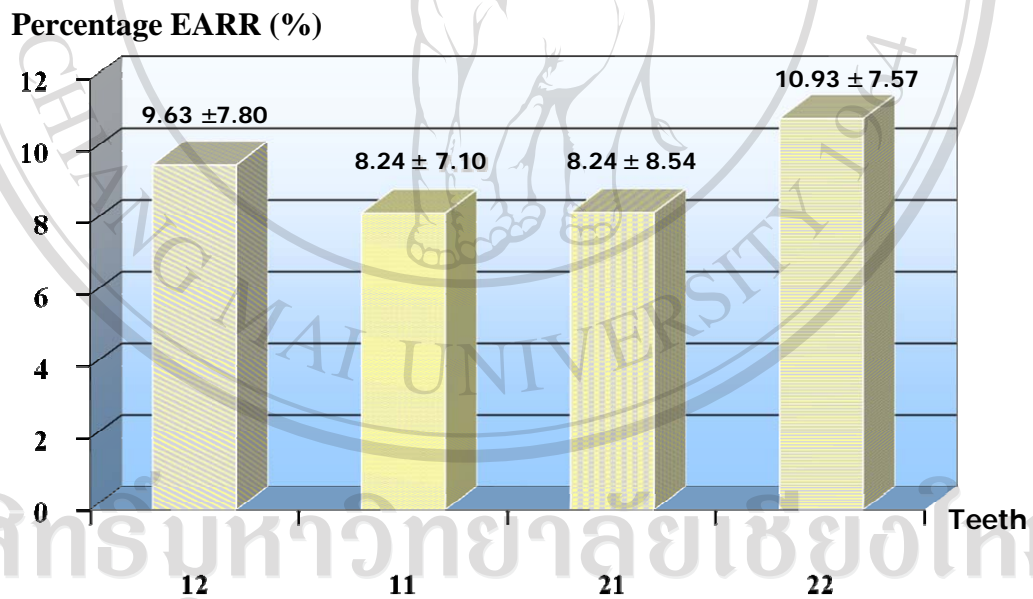


Figure 4.4 Mean percentage of EARR per tooth in each maxillary incisor (11, 12, 21, 22)

The most resorbed tooth was resorbed 11.72 mm or 66.43% of root length. There were two teeth which had no root resorption. Surprisingly, there were eight teeth which had increased root length.

The minimum amounts of EARR in the right central and lateral, left central and lateral incisors were -0.84, -0.1, -1.68 and -0.09 mm, respectively. The minimum

percentages of EARR per tooth were -5.90, -0.54, -8.86 and -0.45 per cent, respectively. The maximum amounts of EARR were 6.76, 5.37, 11.7 and 6.53 mm, respectively. And the maximum percentages of EARR per tooth were 39.9, 38.6, 66.43 and 40.4 percents, respectively (Table 4.2). The most resorbed tooth was a central incisor in a 15-year-old male patient (11.7 mm. or 66.4%) who had a history of trauma, a large (10 mm) overjet and a deep (5 mm) overbite. The most elongated root was a central incisor in a 14-year-old female patient (1.68 mm. or 11.82%) who had a tongue-thrusting habit, a large (8 mm) overjet and a deep (4 mm) overbite.

Table 4.2 Maximum and minimum amounts of EARR and percentages of EARR per tooth in each maxillary incisor (11, 12, 21, 22)

Maxillary incisor	12		11		21		22	
	Max	Min	Max	Min	Max	Min	Max	Min
Amount of root resorption (mm)	5.37	-0.1	6.76	-0.84	11.7	-1.68	6.53	-0.09
Percentage root resorption per tooth	38.6	-0.54	39.9	-5.90	66.4	-11.82	40.4	-0.45
<i>Number of teeth</i>	131		150		149		134	

The maxillary lateral incisor demonstrated more EARR than did the maxillary central incisor. The mean amount and mean percentage of EARR in maxillary central incisors was 1.39 ± 1.27 mm. and $8.24 \pm 7.22\%$, respectively. The corresponding values in maxillary lateral incisors were 1.69 ± 1.14 mm and $10.16 \pm 6.78\%$, respectively (Table 4.3, Figures 4.5 and 4.6).

Table 4.3 Mean EARR (mm) and mean percentage of EARR per tooth in maxillary central and lateral incisors

Tooth	n	Mean amount of EARR ± SD (mm)	Mean percentage of EARR per tooth ± SD
Maxillary central incisor	299	1.39±1.27	8.24±7.22
Maxillary lateral incisor	265	1.69±1.14	10.16±6.78

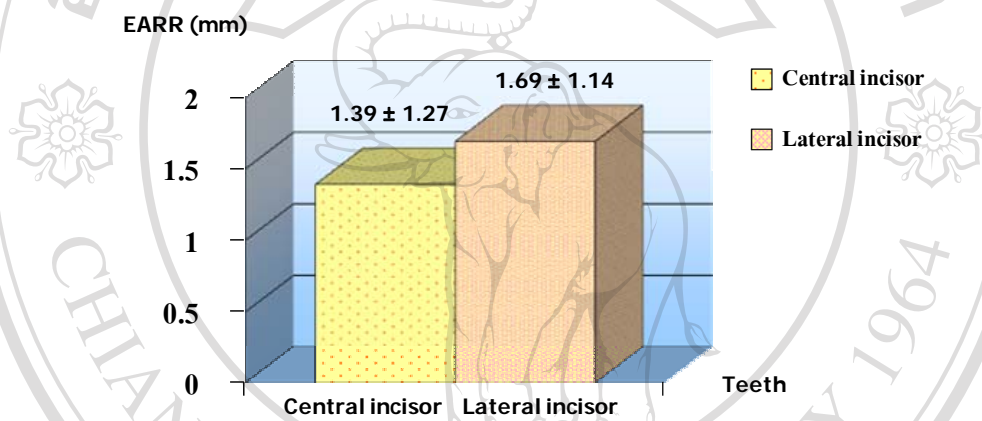


Figure 4.5 Mean amount EARR (mm) in maxillary central and lateral incisors

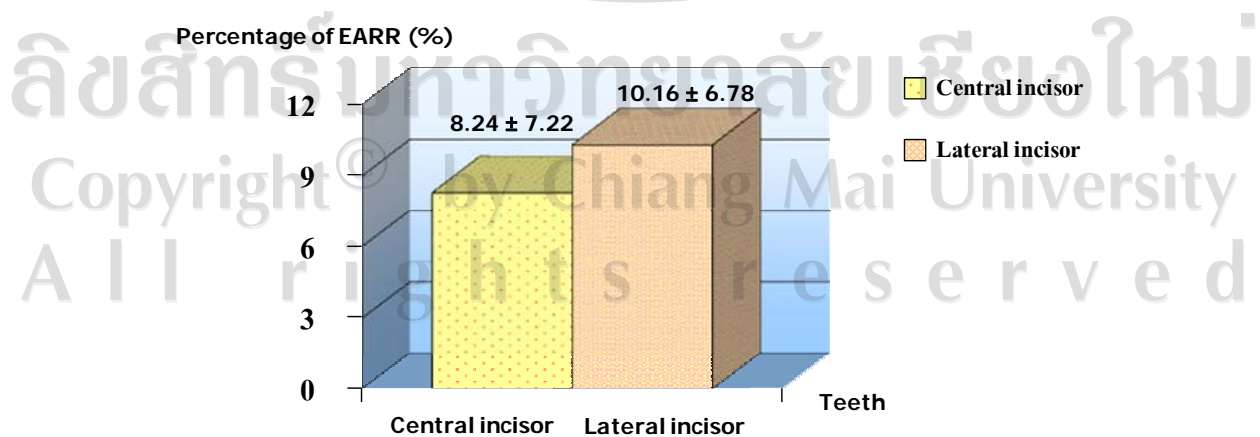


Figure 4.6 Mean percentage of EARR in maxillary central and lateral incisors

The mean EARR in maxillary lateral incisors was more than that in maxillary central incisors. A Paired sample-*t*-test showed statistically significant differences between central and lateral incisors at $P < .05$ (Table 4.4).

Table 4.4 Comparison of the mean amount and mean percentage of EARR between maxillary central and lateral incisors (Paired-sample *t*-tests)

	Maxillary incisors		P- value
	Central	Lateral	
Mean amount EARR (mm)	1.42±1.2	1.71±1.15	0.003*
Mean percentage of EARR per tooth	8.53±7.22	10.34±6.87	0.001*
Number of teeth	142	142	

* $P < .05$

The results showed that 59.6% of the investigated teeth expressed mild EARR, 31.9% were classified as moderate EARR, and 8.5% had severe EARR. (Figure 4.7)

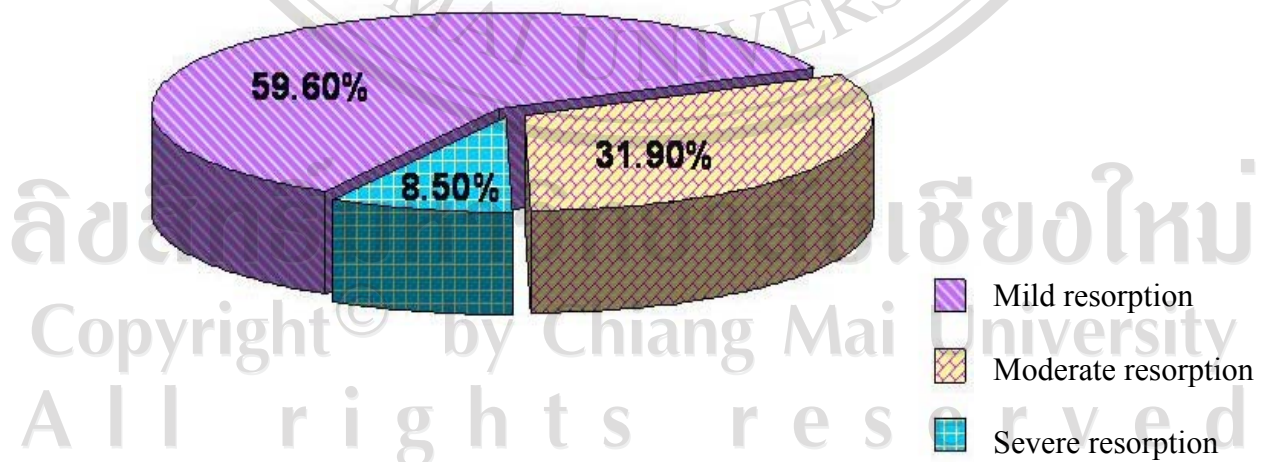


Figure 4.7 Degrees of external apical root resorption

II. Factors associated with external apical root resorption

Distribution of EARR in each examination factor was considered for normality of distribution using histograms. However, the assumption of normality could not be made for each group within every examination factor. Therefore, data were summarized as medians and compared using nonparametric tests: Mann-Whitney U test (2 groups) or Kruskal-Wallis test (more than 2 groups). However, means were also calculated in order to compare them to the median in each group.

Of all of the factors examined in this study, age at start of treatment, overjet, root shape, history of trauma, allergic condition, treatment planning (non-extraction/extraction cases) and treatment duration showed statistically significant differences in EARR within groups. However, sex of subjects, overbite, tongue-thrusting habit, types of malocclusion and types of bracket were not associated with EARR (Table 4.5).

Table 4.5 Associated factors and their significance levels of difference in mean percentage of EARR per tooth (Mann-Whitney U and Kruskal-Wallis H test)

Examination factors	Unit	<i>p</i> -value
Sex	Male/Female	0.378
Age at start of treatment	Years (≤ 16 / > 16)	0.025*
Overjet	mm. (< 1 , 1-4, > 4 -6, > 6)	0.038*
Overbite	mm. (≤ 0 , > 0 -3, > 3 -5, > 5)	0.499
Root shape	Normal/Abnormal	< 0.001 ***
History of trauma	Yes/no	0.014*
Tongue-thrusting habit	Yes/no	0.411
Allergic condition	Yes/no	0.003**
Types of malocclusion	CI I, II, III	0.946
Treatment planning	Non-Extraction / extraction	< 0.001 ***
Types of bracket	Standard / Pre-adjusted	0.748
Treatment duration	Months (1-12, 13-24, 25-36, ≥ 37)	< 0.001 ***

* $P < .05$, ** $P < .01$, *** $P < .001$

- Sex

There were 62 male and 119 female patients in this study. One hundred and eighty two investigated teeth were in male patients and 382 were in female patients. There was a normal distribution of data for EARR among female patients but there was not a normal distribution among male patients as illustrated in histograms (Figures 4.8 and 4.9).

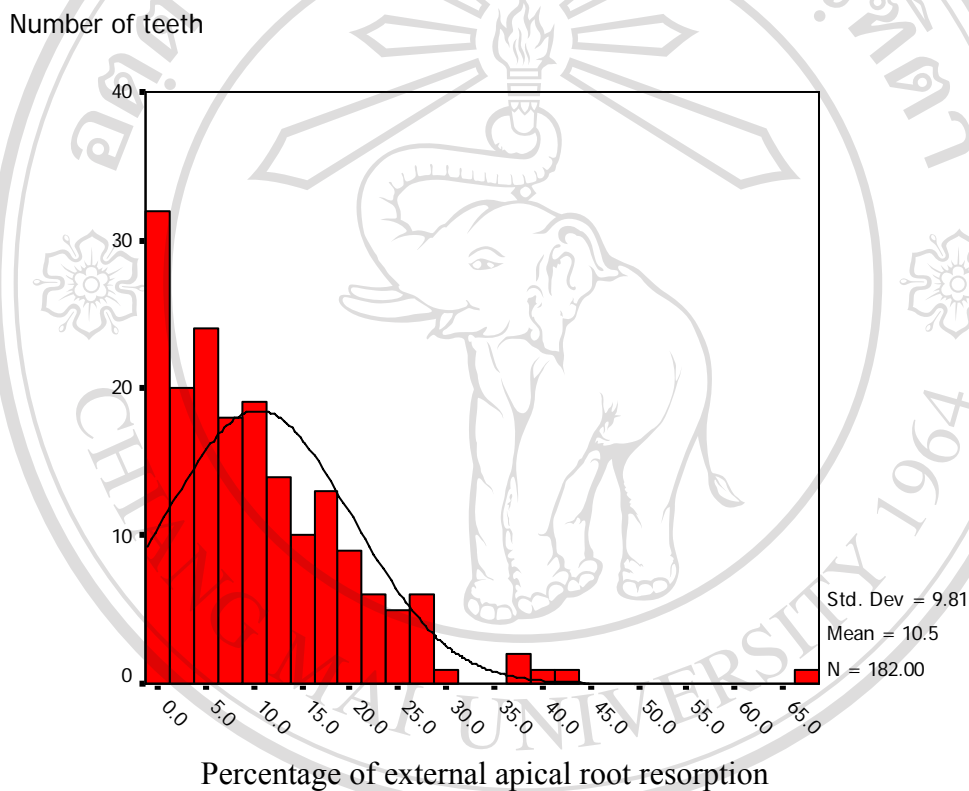


Figure 4.8 Histogram showing percentage of EARR in 182 teeth in male patients

Number of teeth

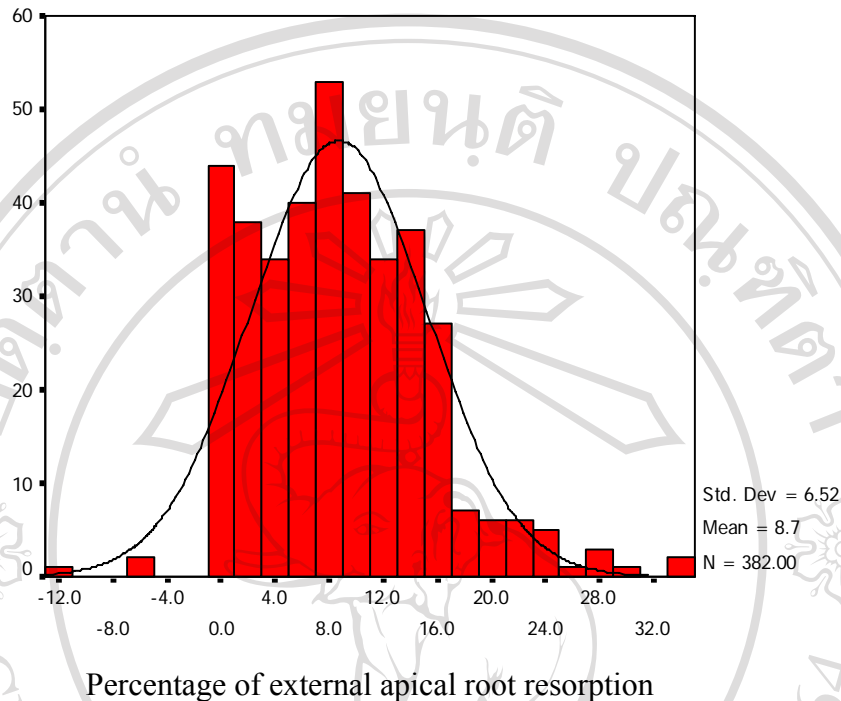


Figure 4.9 Histogram showing percentage of EARR in 382 teeth in female patients

The maximum EARR in male and female patients were 11.72 mm (66.43%) and 5.24 mm (34.70%), respectively. The minimum EARR in male and female patients were -0.1 mm (-0.54%) and -1.68 mm (-11.82%), respectively (Table 4.6). The most resorbed tooth in male patients was a incisor which had history of trauma, a large overjet and a deep overbite.

Table 4.6 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in male and female patients

Sex	Male		Female	
	Maximum	Minimum	Maximum	Minimum
Amount of EARR (mm)	11.72	-0.1	5.24	-1.68
Percentage of EARR per tooth	66.43	-0.54	34.70	-11.82
<i>Number of teeth</i>	182		382	

There was a slight difference in medians and means of EARR in each group. median amount of EARR and median percentage of EARR per tooth were 1.25 mm (8.03%) and 1.37mm (8.09%) in male and female patients, respectively. The mean amounts and mean percentages of EARR per tooth were 1.74±1.66 mm (10.45±9.81%) and 1.45±1.07 mm (8.70±6.52%) in male and female patients, respectively. However, the distribution of EARR data in male and female groups was not normal; therefore, medians were used as representative root resorption data in male and female groups.

Although medians and means of EARR showed differences in both amount and percentage between male and female patients, statistical calculations showed no significant differences. The medians and means of EARR in millimeters and the percentages of EARR per tooth in both female and male patients are shown in Table 4.7.

Table 4.7 Medians, interquartile ranges, means and standard deviations of post-treatment EARR of maxillary incisors in male and female patients and their *P*-values (Mann-Whitney U test)

Sex		Male	Female	<i>P</i> -value
Amount of EARR (mm)	Median	1.25	1.37	0.416
	(Interquartile range)	(2.31)	(1.49)	
	Mean ± SD	1.74±1.66	1.45±1.07	
Percentage of EARR per tooth	Median	8.03	8.09	0.378
	(Interquartile range)	(13.24)	(9.09)	
	Mean	10.45±9.81	8.70±6.52	
<i>Number of teeth</i>		182	382	

- **Age at start of treatment**

Mean treatment starting age of samples in this study was 16.23 ± 4.75 years (range from 10 to 46 years). There was a normal distribution of data for age at start of treatment among 181 patients as illustrated in Figure 4.10.

Number of patients

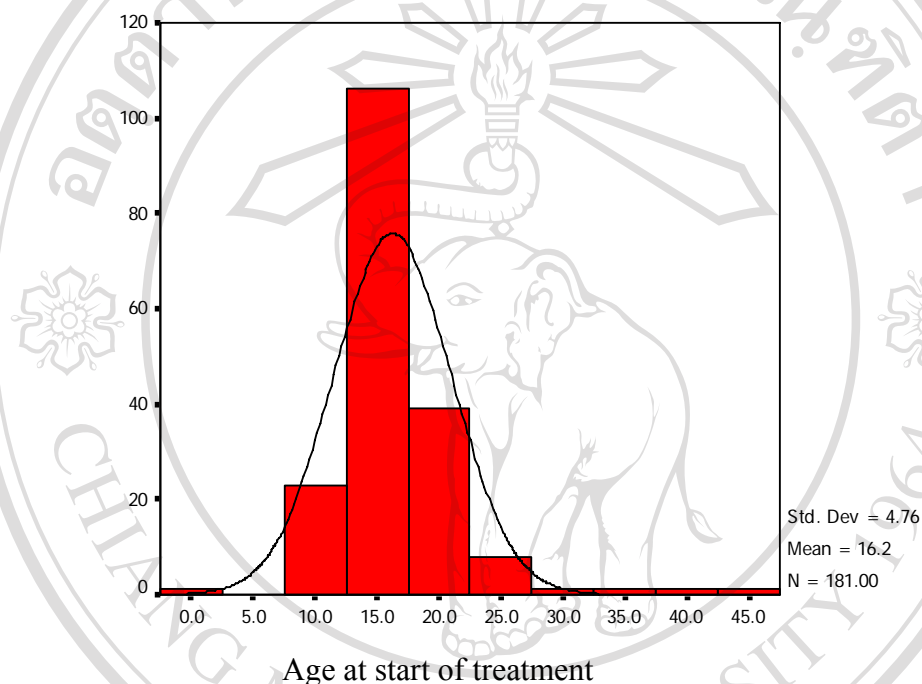


Figure 4.10 Histogram showing age at start of treatment in 181 patients

This study classified age at start of treatment into 2 groups, ≤ 16 -year-old and > 16 -year-old groups, following the growth pattern of northern Thai children in the study of Nabangxang et al,⁷⁵ assuming that patients in the ≤ 16 -year-old group were in the growth period and that patients in the > 16 -year-old group were after the growth period. There was asymmetric distribution of percentage root resorption per tooth in both age groups as illustrated in Figures 4.11 and 4.12.

Number of teeth

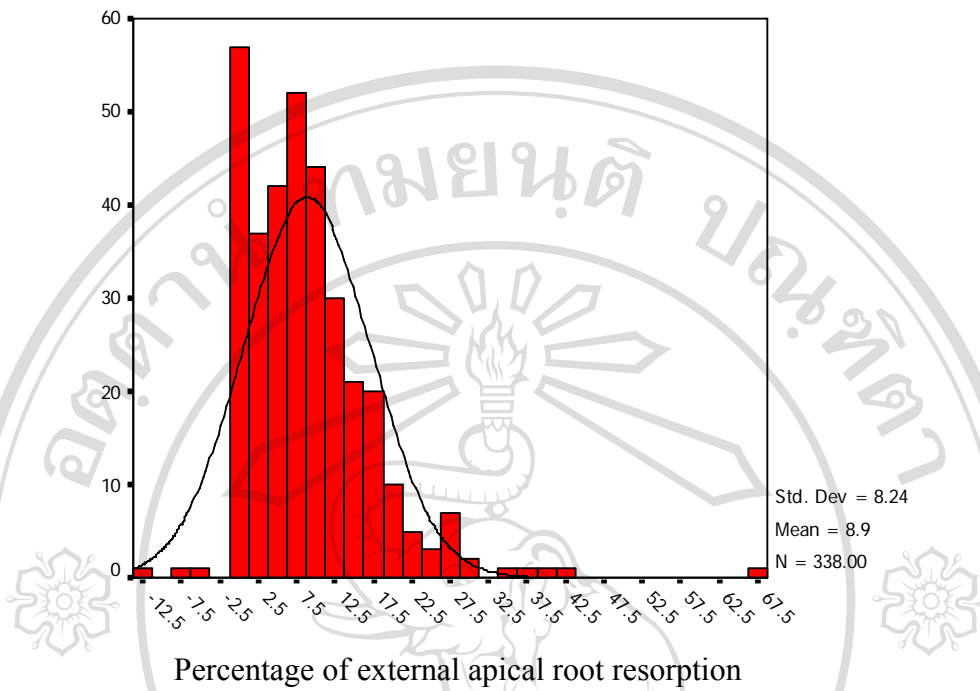


Figure 4.11 Histogram showing percentage of EARR in the ≤16 year old group

Number of teeth

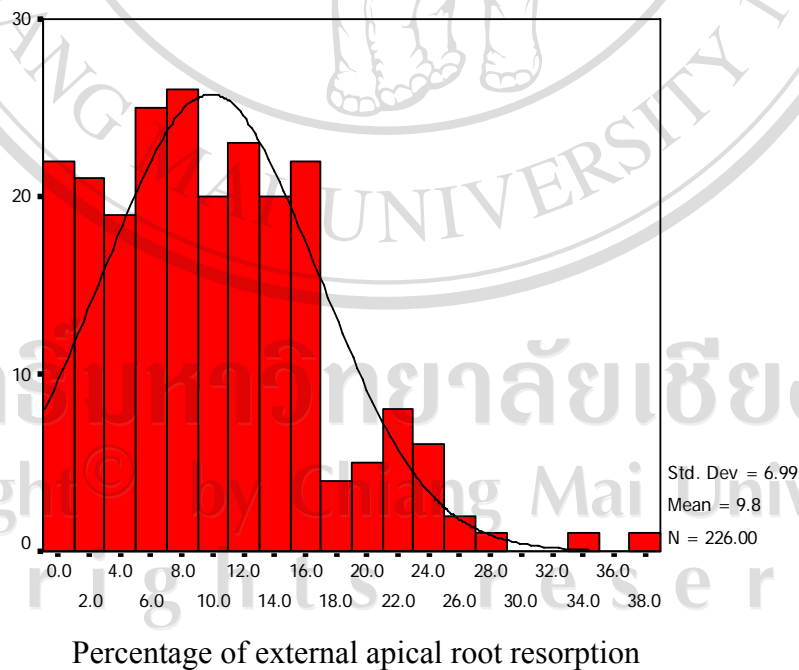


Figure 4.12 Histogram showing percentage of EARR in the >16 year old group

The minimum amounts of EARR in the ≤16-year-old and >16-year-old groups were -1.68 and -0.03 mm, respectively. The minimum percentages of EARR per

tooth were -11.82% and -0.20%, respectively. The maximum amounts of EARR were 11.72 and 5.24 mm, respectively. And the maximum percentages of EARR per tooth were 66.43% and 38.41%, respectively (Table 4.8).

Table 4.8 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in each age group

Age group	≤16 years old		>16 years old	
	Maximum	Minimum	Maximum	Minimum
Amount of EARR (mm)	11.72	-1.68	5.24	-0.03
Percentage of EARR per tooth	66.43	-11.82	38.41	-0.20
<i>Number of teeth</i>	338		226	

The values of medians and means for both amount and percentage of EARR were nearly similar. The median amounts median percentages of EARR were 1.32 mm (7.79%) and 1.48 mm (9.00%) in the ≤16-year-old and the >16-year-old groups, respectively. The mean amounts of EARR in the ≤16-year-old and the >16-year-old groups were 1.49±1.40 mm and 1.62±1.14 mm, respectively. Mean percentages of EARR per tooth were 8.87±8.24% and 9.85±6.99%, respectively. However, the distribution of EARR data in the ≤16-year-old and the >16-year-old groups was not normal. Therefore, the median was more representative of EARR data than the mean in each age group.

Interestingly, the Mann-Whitney U test found statistically significant differences in median values of EARR between each group, ($P < .05$). The median and mean values of EARR in millimeters and the percentages of EARR per tooth in both age groups are shown in Table 4.9.

Table 4.9 Medians, interquartile ranges, means and standard deviations of post-treatment EARR of maxillary incisors in each age group and their *P*-values (Mann-Whitney U test)

Age group		≤16 years old	>16 years old	<i>P</i> -value
Amount of EARR (mm)	Median	1.32	1.48	0.036*
	(Interquartile range)	(1.68)	(1.63)	
	Mean	1.49±1.40	1.62±1.14	
Percentage of EARR per tooth	Median	7.79	9.00	0.025*
	(Interquartile range)	(10.12)	(9.93)	
	Mean	8.87±8.24	9.85±6.99	
<i>Number of teeth</i>		338	226	

**P* < .05

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• Overjet

In this study, the overjet ranged from -5 to 12 millimeters. The mean of overjet was 3.79 ± 3.01 mm. However, overjet was divided into four groups according to its severity: negative group (less than 1 mm), normal group (1 to 4 mm), moderate group (> 4 to 6 mm) and severe group (greater than 6 mm). There was an asymmetric distribution of data for percentage of EARR in each overjet group as illustrated in Figures 4.13, 4.14, 4.15 and 4.16.

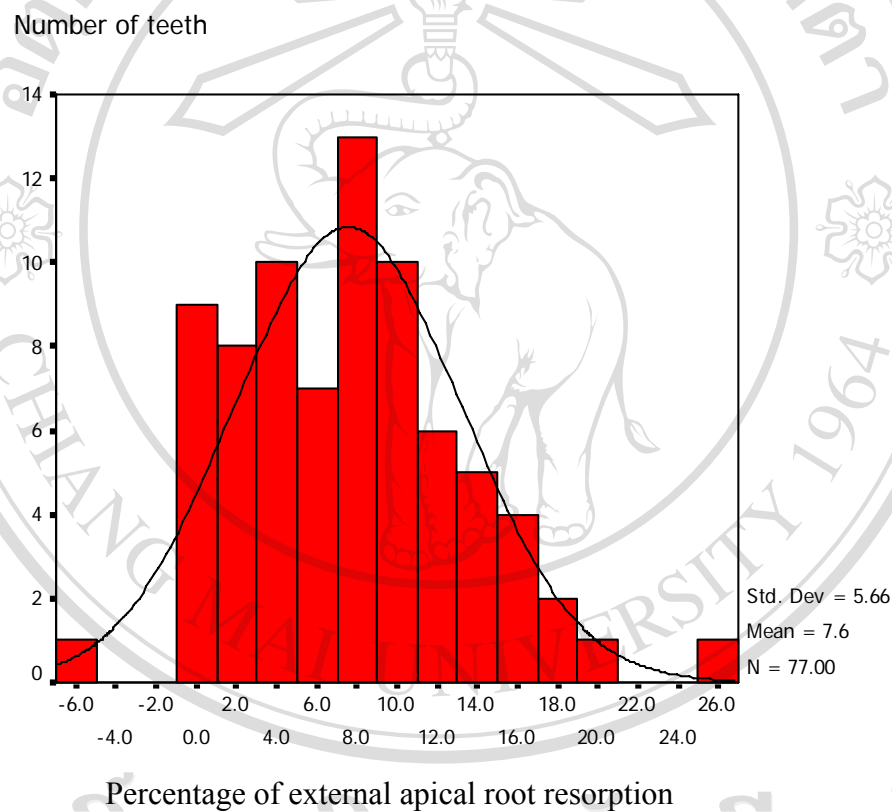


Figure 4.13 Histogram showing percentage of EARR in maxillary incisors the <1 mm overjet group

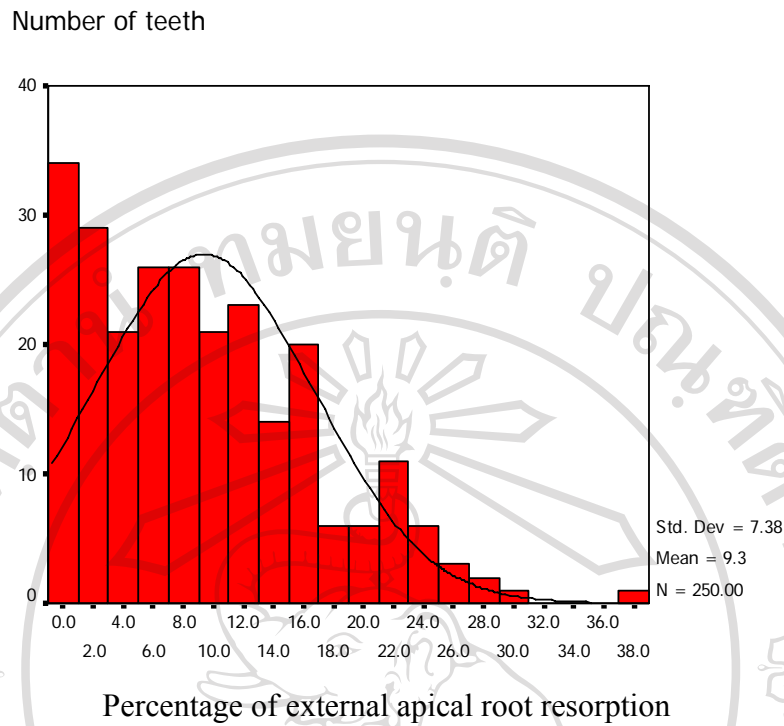


Figure 4.14 Histogram showing percentage of EARR in maxillary incisors in the 1-4 mm overjet group

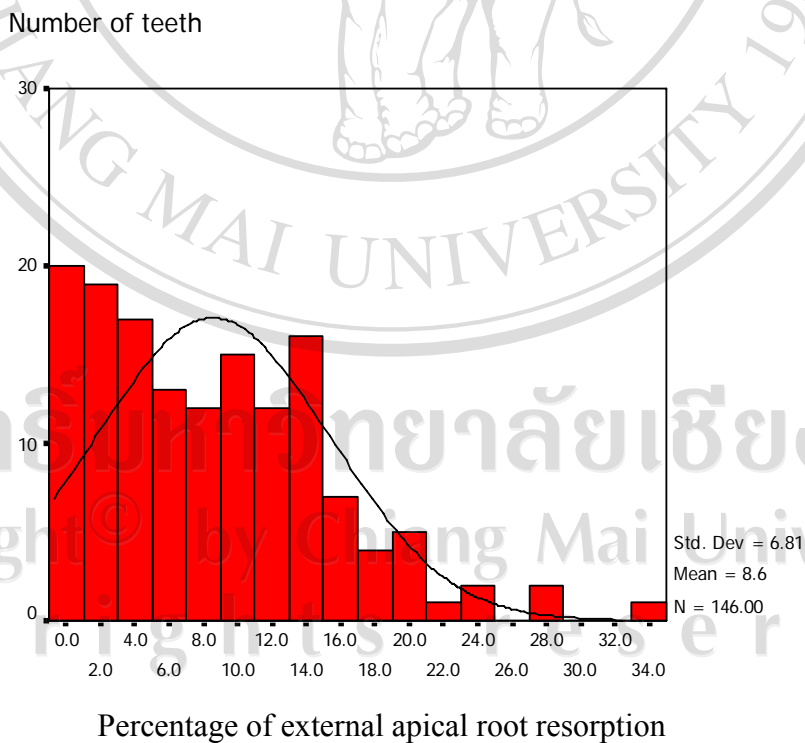


Figure 4.15 Histogram showing percentage of EARR in maxillary incisors in the >4-6 mm overjet group

Number of teeth

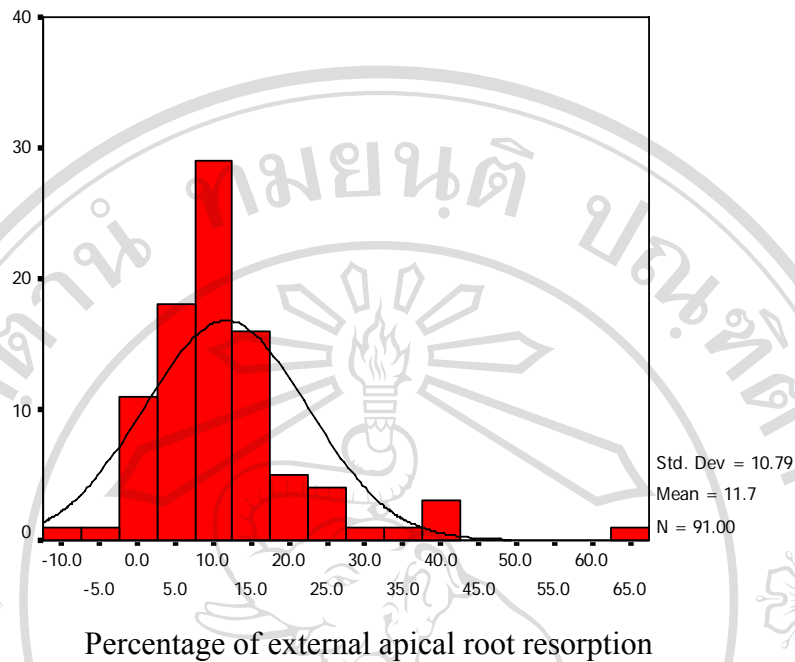


Figure 4.16 Histogram showing percentage of EARR in maxillary incisors in the >6 mm overjet group

The minimum amounts of EARR in each overjet group were -0.9, 0, -0.1 and -1.7 mm, respectively. The minimum percentages of EARR per tooth were -6.3, 0.03, -0.56 and -11.8 per cent, respectively. The maximum amounts of EARR were 5, 5.36, 4.8 and 11.7 mm, respectively. And the maximum percentages of EARR per tooth were 26.1, 38.4, 33.8 and 66.4 per cent, respectively (Table 4.10).

Table 4.10 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in each overjet group

Overjet group	<1		1-4		>4-6		>6	
	Max	Min	Max	Min	Max	Min	Max	Min
Amount of EARR (mm)	5.0	-0.9	5.36	0	4.8	-0.1	11.7	-1.7
Percentage of EARR per tooth	26.1	-6.3	38.4	0.03	33.8	-0.56	66.4	-11.8
<i>Number of teeth</i>	77		250		146		91	

There was a tendency towards increasing maximum value according to the severity of overjet, except in the moderate overjet group (>4-6 mm), where the maximum value was lower than that in the normal group (overjet 1-4 mm). This tendency was similar to that for the median and mean percentage of EARR in each group.

The distribution of EARR data in each overjet group of was not normal. Therefore, the medians were used as representative root resorption data for each overjet group. The median amounts of EARR in each overjet group were 1.22, 1.27, 1.42 and 1.62 mm, respectively. The median percentages of EARR per tooth were 7.68, 8.09, 7.70 and 9.56 per cent, respectively. However, the mean EARR was also calculated and compared to the median of EARR in each overjet group. The mean amounts of EARR were 1.25 ± 0.98 , 1.50 ± 1.20 , 1.48 ± 1.15 and 1.99 ± 1.84 mm, respectively. Mean percentages of EARR per tooth were 7.55 ± 5.66 , 9.34 ± 7.38 , 8.56 ± 6.81 and 11.67 ± 10.8 per cent, respectively.

Kruskal-Wallis calculation found statistically significant differences in median EARR between each group, ($P < .05$). (Table 4.11) Although median and mean percentage of EARR per tooth in the moderate overjet group (>4-6 mm) were lower than those in the normal overjet group (1-4 mm), there was no statistical difference between these two groups.

Table 4.11 Medians, interquartile ranges, means and standard deviations of post-treatment EARR in maxillary incisors in various overjet groups and their P -values (Kruskal-Wallis H test)

Overjet group		<1	1-4	>4-6	>6	P -value
Amount of EARR (mm)	Median	1.22	1.27	1.42	1.62	0.032*
	(Interquartile range)	(1.33)	(1.73)	(1.76)	(1.48)	
	Mean	1.25 ± 0.98	1.50 ± 1.20	1.48 ± 1.15	1.99 ± 1.84	
Percentage of EARR per tooth	Median	7.68	8.09	7.70	9.56	0.038*
	(Interquartile range)	(7.71)	(11.03)	(10.36)	(10.94)	
	Mean	7.55 ± 5.66	9.34 ± 7.38	8.56 ± 6.81	11.67 ± 10.8	
<i>Number of teeth</i>		77	250	146	91	

$P < .05$

There was no statistically significant difference between the normal overjet and other overjet groups. Interestingly, there was a highly significant difference in median and mean EARR between the severe overjet group (>6 mm) and other groups. The median amounts EARR and median percentages of EARR per tooth were 1.31 mm (7.86%) and 1.62 mm (9.56%) in the ≤6 mm overjet and the >6 mm overjet groups, respectively. The mean amounts of EARR were 1.46±1.15 and 1.99±1.84 mm, respectively. The mean percentages of EARR per tooth were 8.81±6.97% and 11.67±10.79%, respectively. Mann-Whitney U tests showed highly statistically significant differences between each group (Table 4.12).

Table 4.12 Medians, interquartile ranges, means and standard deviations of post-treatment EARR in maxillary incisors in the ≤6 and >6 overjet groups and their P-values (Mann-Whitney U test)

Overjet group		≤6	>6	P-value
Amount of EARR (mm)	Median	1.31	1.62	0.008**
	(Interquartile range)	(1.71)	(1.48)	
	Mean	1.46±1.15	1.99±1.84	
Percentage of EARR per tooth	Median	7.86	9.56	0.012*
	(Interquartile range)	(10.29)	(7.94)	
	Mean	8.81±6.97	11.67±10.79	
<i>Number of teeth</i>		473	91	

* $P < .05$, ** $P < .01$

• Overbite

In the investigated cases the overbite ranged from -3 to 10 mm. The mean overbite was 3.02 ± 1.86 mm. Overbite was divided into four groups according to its severity: negative group (overbite ≤ 0 mm.), normal group (>0 to 3 mm.), moderate group (>3 to 5 mm) and severe group (>5 mm.). There were asymmetric distribution of data for percentage of EARR in each overbite group as illustrated in Figures 4.17, 4.18, 4.19 and 4.20.

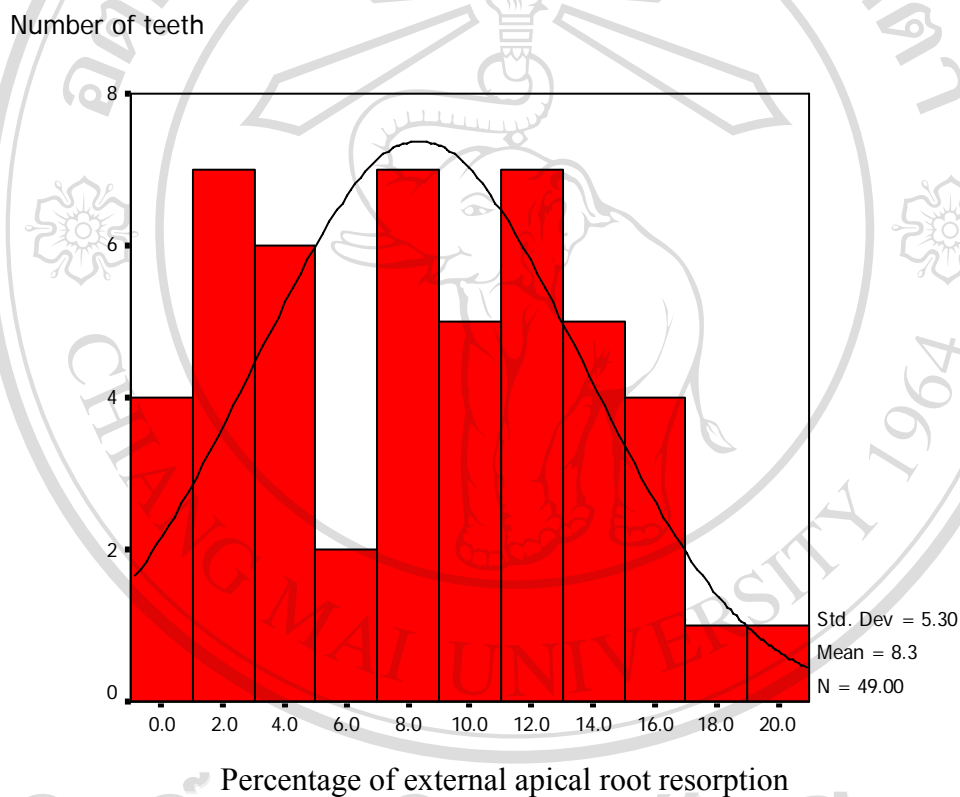


Figure 4.17 Histogram showing percentage of EARR in maxillary incisors in the negative overbite (≤ 0 mm) group

Number of teeth

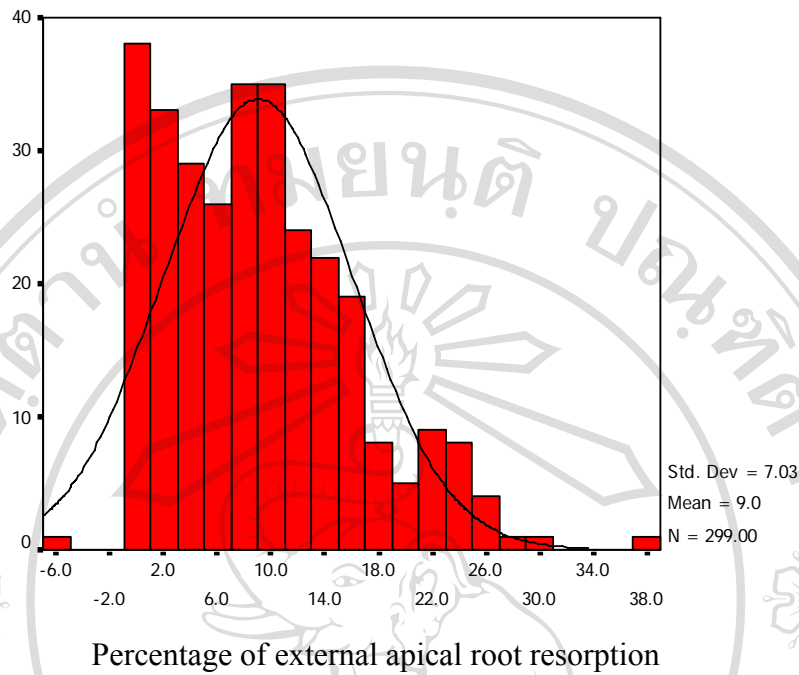


Figure 4.18 Histogram showing percentage of EARR in maxillary incisors in the normal overbite (>0 to 3 mm) group

Number of teeth

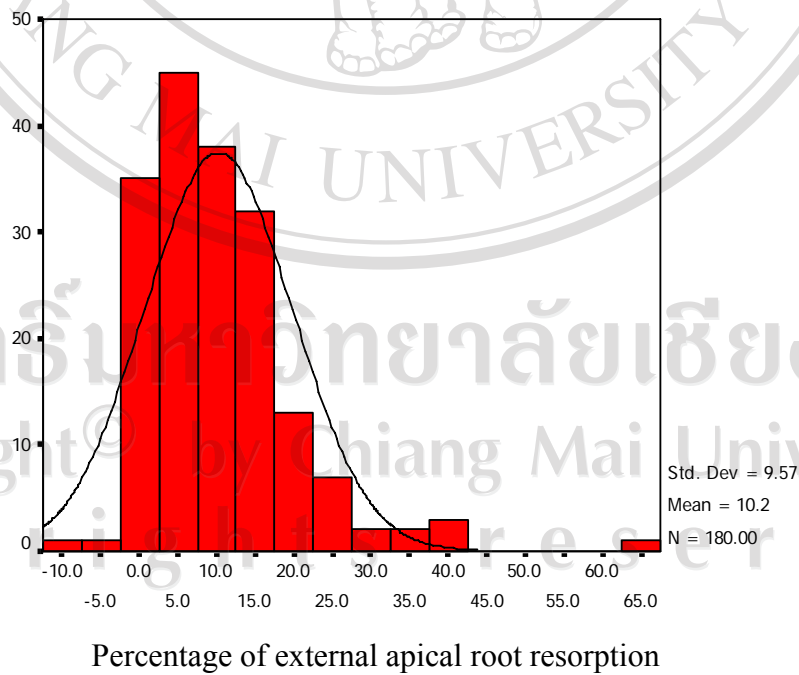


Figure 4.19 Histogram showing percentage of EARR in maxillary incisors in the moderate overbite (>3 to 5 mm) group

Number of teeth

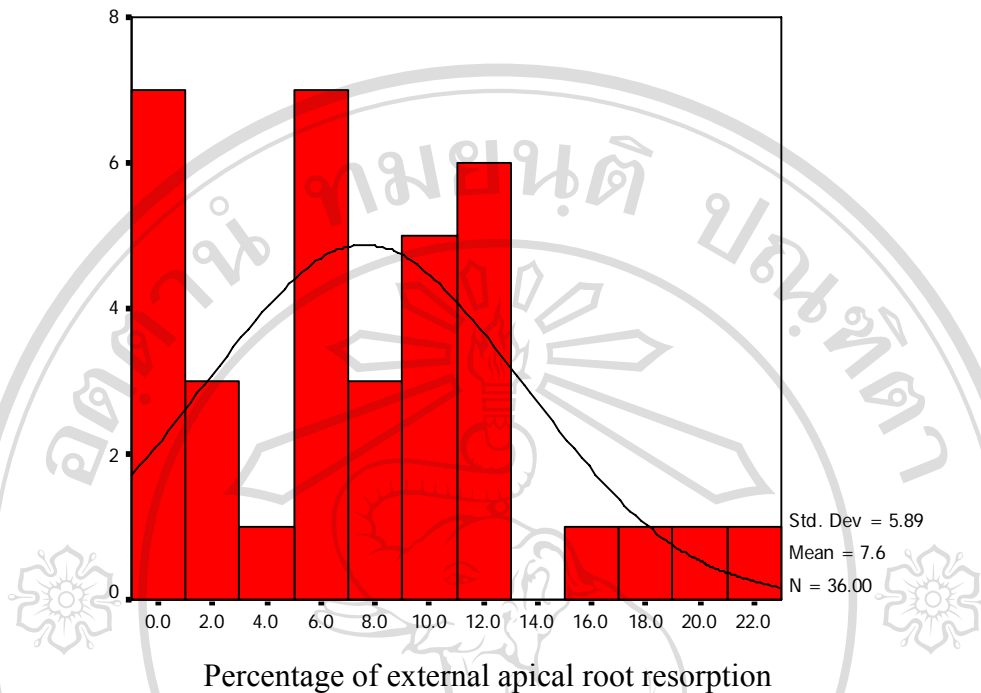


Figure 4.20 Histogram showing percentage of EARR in maxillary incisors in the severe overbite (> 5 mm.) group

The minimum amounts of EARR in each overbite group were 0.03, -0.91, -1.68 and -0.1 mm., respectively. The minimum percentages of EARR per tooth were 0.19, -6.31, -11.8 and -0.5 per cents, respectively. The maximum amounts of EARR were 3.57, 5.36, 11.7 and 3.06 mm, respectively. And the maximum percentages of EARR per tooth were 19.2, 38.4, 66.4 and 21.5 per cent, respectively (Table 4.13).

Table 4.13 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in each overbite group

Overbite group	≤0		>0-3		>3-5		>5	
	Max	Min	Max	Min	Max	Min	Max	Min
Amount of EARR (mm)	3.57	0.03	5.36	-0.91	11.7	-1.68	3.06	-0.1
Percentage of EARR per tooth	19.2	0.19	38.4	-6.31	66.4	-11.8	21.5	-0.5
<i>Number of teeth</i>	49		299		180		36	

The distribution of EARR data in each overbite group was not normal. Therefore, medians were used as representative root resorption data for each overbite group. The median amounts of EARR in each overbite group were 1.39, 1.31, 1.42 and 1.33 mm, respectively. The median percentages of EARR per tooth were 8.22, 8.08, 8.34 and 7.32 per cent, respectively.

However, the means of EARR were also calculated and compared to the medians of EARR in each overbite group. The mean amounts of EARR were 1.41 ± 0.89 , 1.48 ± 1.2 , 1.73 ± 1.59 and 1.25 ± 0.9 mm, respectively. The mean percentages of EARR per tooth were 8.34 ± 5.3 , 9.04 ± 7.0 , 10.24 ± 9.6 and 7.59 ± 5.89 per cent, respectively.

There were no statistically significant differences in median amounts and median percentages of EARR between each group (Table 4.14).

Table 4.14 Medians, interquartile ranges, means and standard deviations of post-treatment EARR in maxillary incisors in various overbite groups and their *P*-values (Kruskal-Wallis H test)

Overbite group		≤0	>0-3	>3-5	>5	<i>P</i> -value
Amount of EARR (mm)	Median	1.39	1.31	1.42	1.33	0.359
	(Interquartile range)	(1.42)	(1.62)	(1.85)	(1.54)	
	Mean	1.41 ± 0.89	1.48 ± 1.2	1.73 ± 1.59	1.25 ± 0.9	
Percentage of EARR per tooth	Median	8.22	8.08	8.34	7.32	0.499
	(Interquartile range)	(9.56)	(9.42)	(10.42)	(8.91)	
	Mean	8.34 ± 5.3	9.04 ± 7.0	10.24 ± 9.6	7.59 ± 5.89	
<i>Number of teeth</i>		49	299	180	36	

- **Root shape**

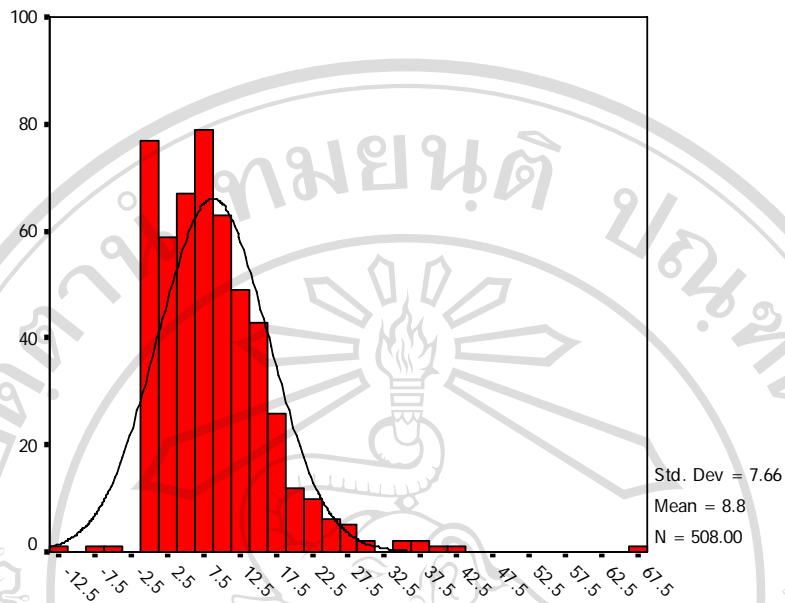
Fifty-six teeth had abnormal root shape (dilacerated or pointed roots), 16 and 40 central and lateral incisors, respectively. All abnormal roots showed some degree of EARR. Figure 4.21 shows images of a lateral incisor with a dilacerated root before orthodontic treatment (A) and with resorption of the root after the end of an orthodontic treatment course (B).



Figure 4.21 Periapical radiographs of a dilacerated maxillary lateral incisor; A. Before treatment, B. After treatment

There were asymmetric distributions of data for percentage of EARR in maxillary incisors with normal and abnormal root shapes (Figures 4.22 and 4.23).

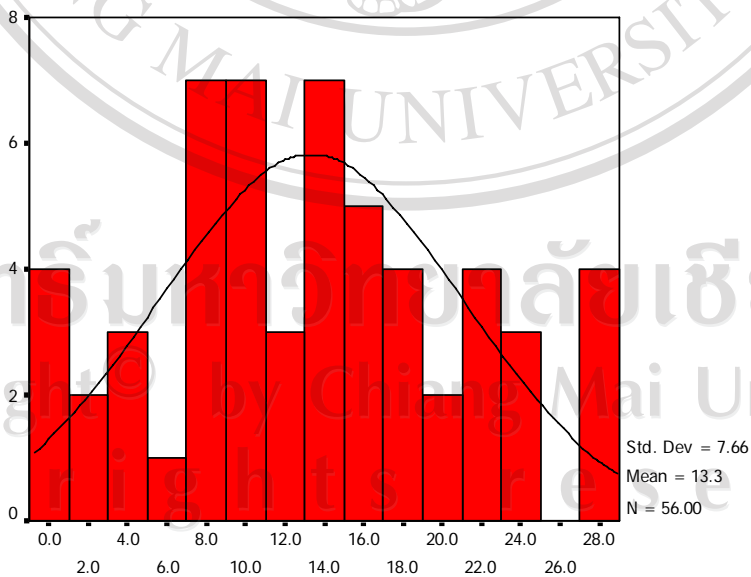
Number of teeth



Percentage of external apical root resorption

Figure 4.22 Histogram showing percentage of EARR in maxillary incisors in the normal root shape group

Number of teeth



Percentage of external apical root resorption

Figure 4.23 Histogram showing percentage of EARR in maxillary incisors in the abnormal (dilacerated or pointed) root shape group

The minimum amounts of EARR in normal and abnormal root shapes were -1.68 and -0.06 mm, respectively. The minimum percentages of EARR per tooth were -11.82% and -0.33%, respectively. The maximum amounts of EARR were 11.72 and 6.26 mm, respectively. The maximum percentages of EARR per tooth were 61.43% and 28.55%, respectively (Table 4.15).

Many factors influence EARR; therefore, the severest root resorption occurred in the normal root shape group, causing the maximum value to be less meaningful as the representative value in either group.

Table 4.15 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in normal and abnormal root shapes

Root shape	Normal root shape		Abnormal root shape	
	Maximum	Minimum	Maximum	Minimum
Amount of EARR (mm)	11.72	-1.68	6.26	-0.06
Percentage of EARR per tooth	61.43	-11.82	28.55	-0.33
<i>Number of teeth</i>	508		56	

Median and mean amounts and percentages of EARR were calculated for the representative data in both groups. Both medians and means showed nearly similar values of EARR. The median amounts of EARR in the normal and abnormal groups were 1.29 and 2.00 mm, respectively. The median percentages of EARR were 7.80% and 13.28%, respectively. The mean amounts of EARR were 1.46 ± 1.27 and 2.25 ± 1.40 mm, respectively. The mean percentages of EARR were $8.82 \pm 7.66\%$ and $13.33 \pm 7.6\%$, respectively.

The results indicated that abnormal root shape was a highly statistically significant factor for EARR over the normal root shape. The medians and means of EARR in millimeters and the percentages of EARR per tooth in both normal and abnormal root shapes are shown in Table 4.16.

Table 4.16 Medians, interquartile ranges, means and standard deviations of post-treatment EARR in maxillary incisors in normal and abnormal root shapes and their *P*-values (Mann-Whitney U test)

Root shape		Normal root shape	Abnormal root shape	<i>P</i> -value
Amount of EARR (mm)	Median	1.29	2.00	< 0.001***
	(Interquartile range)	(1.62)	(1.97)	
	Mean	1.46±1.27	2.25±1.40	
Percentage of EARR per tooth	Median	7.80	13.28	< 0.001***
	(Interquartile range)	(9.76)	(10.89)	
	Mean	8.82±7.66	13.33±7.66	
<i>Number of teeth</i>		508	56	

*** *P* < .001

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- **History of facial trauma**

Nine patients experienced a history of trauma before starting orthodontic treatment. Following the study criteria, 25 maxillary incisors were examined. Figure 4.24 demonstrates severe EARR of the left maxillary central incisor in a patient with a history of facial trauma after orthodontic treatment. The nearby lateral incisor also shows some degree of EARR.

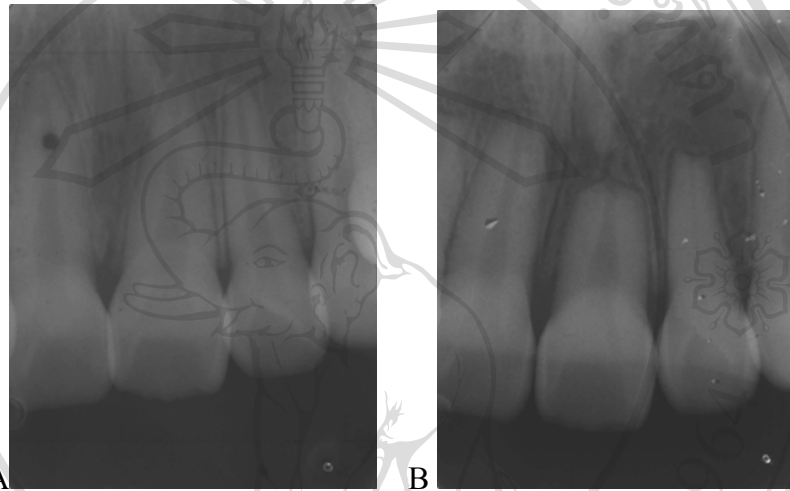


Figure 4.24 Periapical radiographs of previously traumatized maxillary incisors; A. Before treatment, B. After treatment

Five hundred and thirty five teeth were included in the group without a history of trauma and 25 teeth were included in the group with a history of trauma. There were asymmetric distributions of data for percentage of EARR per tooth in maxillary incisors in patients with and without a history of trauma. These are illustrated in Figures 4.27 and 4.28.

Number of teeth

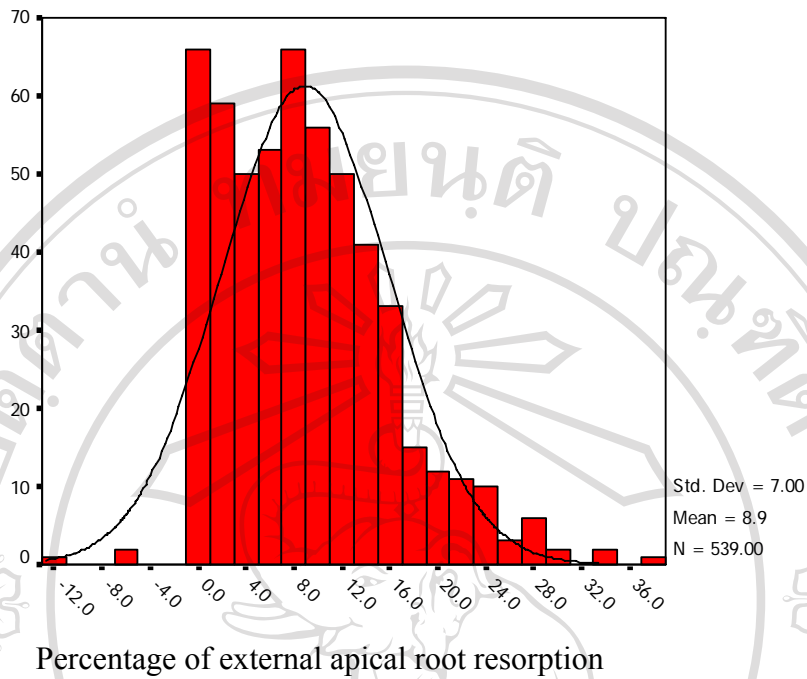


Figure 4.25 Histogram showing percentage of EARR in the group without traumatized maxillary incisors

Number of teeth

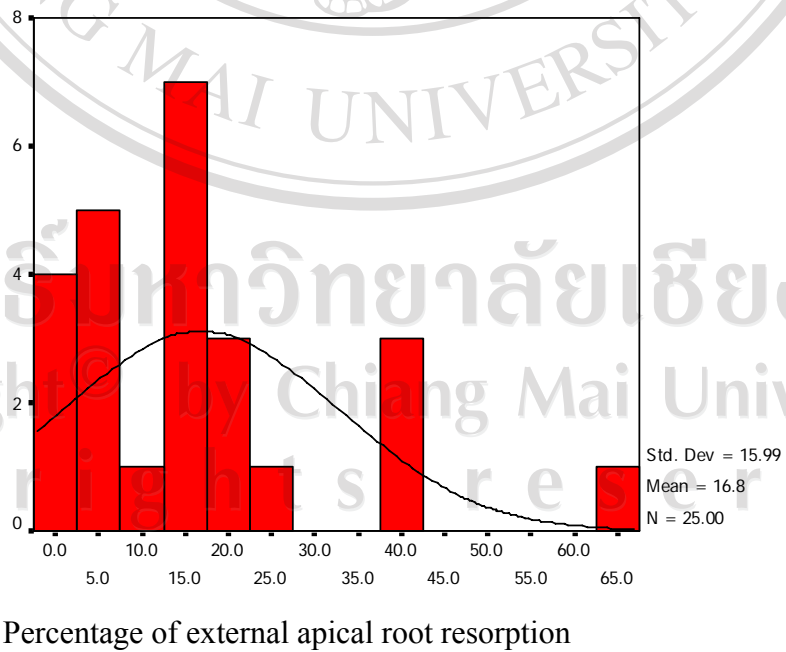


Figure 4.26 Histogram showing percentage of EARR in the group with traumatized maxillary incisors

The minimum amounts of EARR in patients without and with a history of trauma were -1.68 and -0.1 mm, respectively. The minimum percentages of EARR per tooth were -11.82% and -0.7%, respectively. The maximum amounts of EARR were 6.26 and 11.72 mm, respectively. The maximum percentages of EARR per tooth were 38.41% and 66.43%, respectively (Table 4.17).

Table 4.17 Maximum and minimum amounts and percentages of EARR per tooth in maxillary incisors in patients without and with a history of trauma

History of trauma	Without history of trauma		With history of trauma	
	Maximum	Minimum	Maximum	Minimum
Amount of EARR (mm)	6.26	-1.68	11.72	-0.1
Percentage of EARR per tooth	38.41	-11.82	66.43	-0.7
<i>Number of teeth</i>	539		25	

There were slight differences between median and mean amounts and percentages of EARR in both groups. Both medians and means of EARR were higher in the group with a history of trauma than those in the group without a history of trauma. Both means and medians of EARR in the group with a history of trauma were twice those in the group without a history of trauma. The median amounts of EARR in patients without and with a history of trauma were 1.34 and 2.37 mm, respectively. The median percentages of EARR per tooth were 8.07% and 14.75%, respectively. The mean amounts of EARR were 1.48 ± 1.17 and 2.81 ± 2.64 mm, respectively. The mean percentages of EARR per tooth were $8.92 \pm 7.01\%$ and $16.82 \pm 15.99\%$, respectively.

Statistical calculation denoted highly significantly differences of EARR severity between the patients without and with a history of trauma ($P < .05$). The medians and means of EARR in millimeters and the percentages of EARR per tooth in both groups are shown in Table 4.18.

Table 4.18 Medians, interquartile ranges, means and standard deviations of post-treatment EARR in maxillary incisors in patients without and with a history of trauma and their *P*-values (Mann-Whitney U test)

History of trauma		Without history of trauma	With history of trauma	<i>P</i> -value
Amount of EARR (mm)	Median	1.34	2.37	0.006*
	(Interquartile range)	(1.58)	(2.81)	
	Mean	1.48±1.17	2.81±2.64	
Percentage of EARR per tooth	Median	8.07	14.75	0.014*
	(Interquartile range)	(9.84)	(17.31)	
	Mean	8.92±7.01	16.82±15.99	
<i>Number of teeth</i>		539	25	

* *P* < .05

• **Tongue-thrusting habit**

Of the total of 181 patients (564 teeth) sixty-six patients (214 teeth) with a tongue-thrusting habit were recorded before orthodontic treatment. There were asymmetric distribution of data for percentage of EARR per tooth in maxillary incisors in patients without and with a tongue-thrusting habit (Figures 4.27 and 4.28).

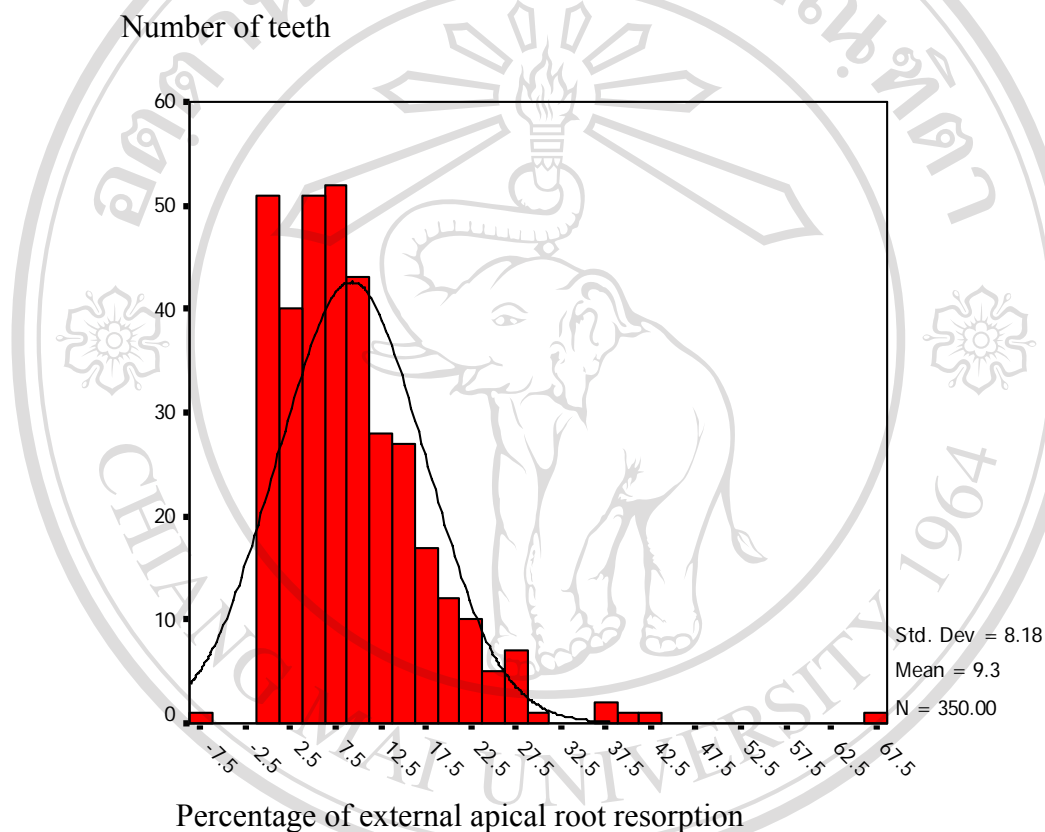
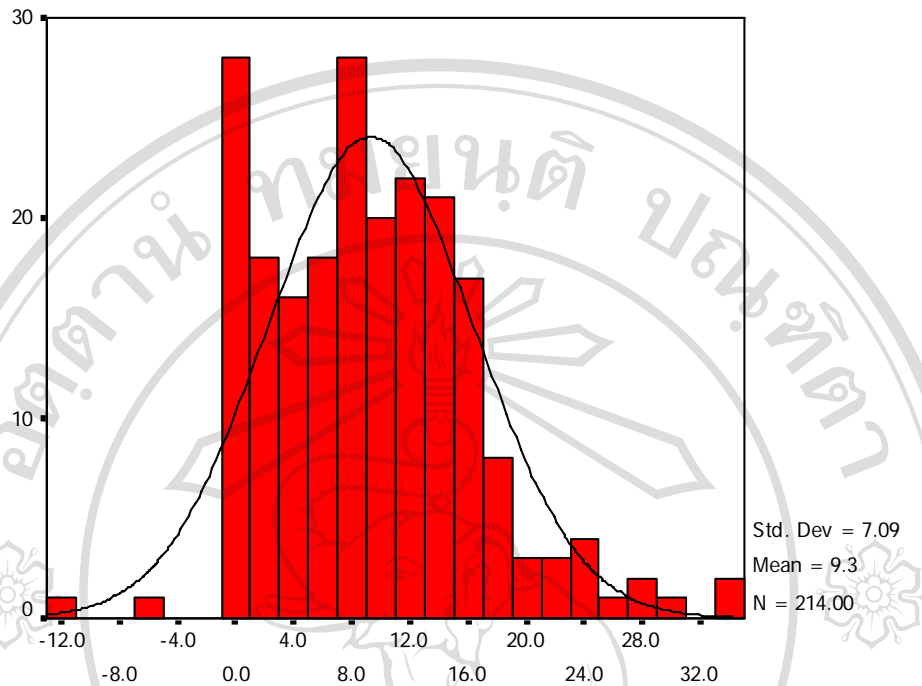


Figure 4.27 Histogram showing percentage of EARR in maxillary incisors in patients without a tongue-thrusting habit

Number of teeth



Percentage of external apical root resorption

Figure 4.28 Histogram showing percentage of EARR in maxillary incisors in patients with a tongue-thrusting habit

The minimum amounts of EARR in patients without and with a tongue-thrusting habit were -0.91 and -1.68 mm, respectively. The minimum percentages of EARR per tooth were -6.31% and -11.82%, respectively. The maximum amounts of EARR were 11.72 and 5.18 mm, respectively. The maximum percentages of EARR per tooth were 66.43% and 34.70%, respectively (Table 4.19).

Table 4.19 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in patients without and with a tongue-thrusting habit

Tongue thrusting habit	Without tongue-thrusting habit		With tongue-thrusting habit	
	Maximum	Minimum	Maximum	Minimum
Amount of EARR (mm)	11.72	-0.91	5.18	-1.68
Percentage of EARR per tooth	66.43	-6.31	34.70	-11.82
<i>Number of teeth</i>	214		350	

Medians and means of amounts and percentages of EARR were calculated to represent the EARR data in each group. The median amounts of EARR in patients without and with a tongue-thrusting habit were 1.25 and 1.53 mm, respectively. The median percentages of EARR were 7.87% and 8.75%, respectively. The mean amounts of EARR were 1.53 ± 1.38 and 1.57 ± 1.16 mm, respectively. The mean percentages of EARR were $9.25 \pm 8.18\%$ and $9.29 \pm 7.09\%$. However, there were asymmetric distributions of data for EARR in both groups. Therefore, medians were used to find any differences between groups. Statistical calculation showed that patients without and with a tongue-thrusting habit did not exhibit different degrees of severity of EARR from each other. The medians and means of EARR in millimeters and the percentages of EARR per tooth in both groups and their significant values are shown in Table 4.20.

Table 4.20 Medians, interquartile ranges, means and standard deviations of post-treatment EARR in maxillary incisors in patients without and with a tongue-thrusting habit and their *P*-values (Mann-Whitney U test)

Tongue-thrusting habit		Without tongue-thrusting habit	With tongue-thrusting habit	<i>P</i> -value
Amount of EARR (mm)	Median	1.25	1.53	0.178
	(Interquartile range)	(1.63)	(1.64)	
	Mean	1.53±1.38	1.57±1.16	
Percentage of EARR per tooth	Median	7.87	8.75	0.411
	(Interquartile range)	(10.01)	(9.89)	
	Mean	9.25±8.18	9.29±7.09	
<i>Number of teeth</i>		350	214	

- **Allergic condition**

There were 31 patients (92 teeth) with allergic conditions and 150 patients (472 teeth) did not have this condition recorded. Individuals with allergic conditions were likely to develop more severe EARR than were those without an allergic history.

There were asymmetric distributions of data for percentages of EARR per tooth in maxillary incisors in patients without and with allergic conditions (Figures 4.29 and 4.30).

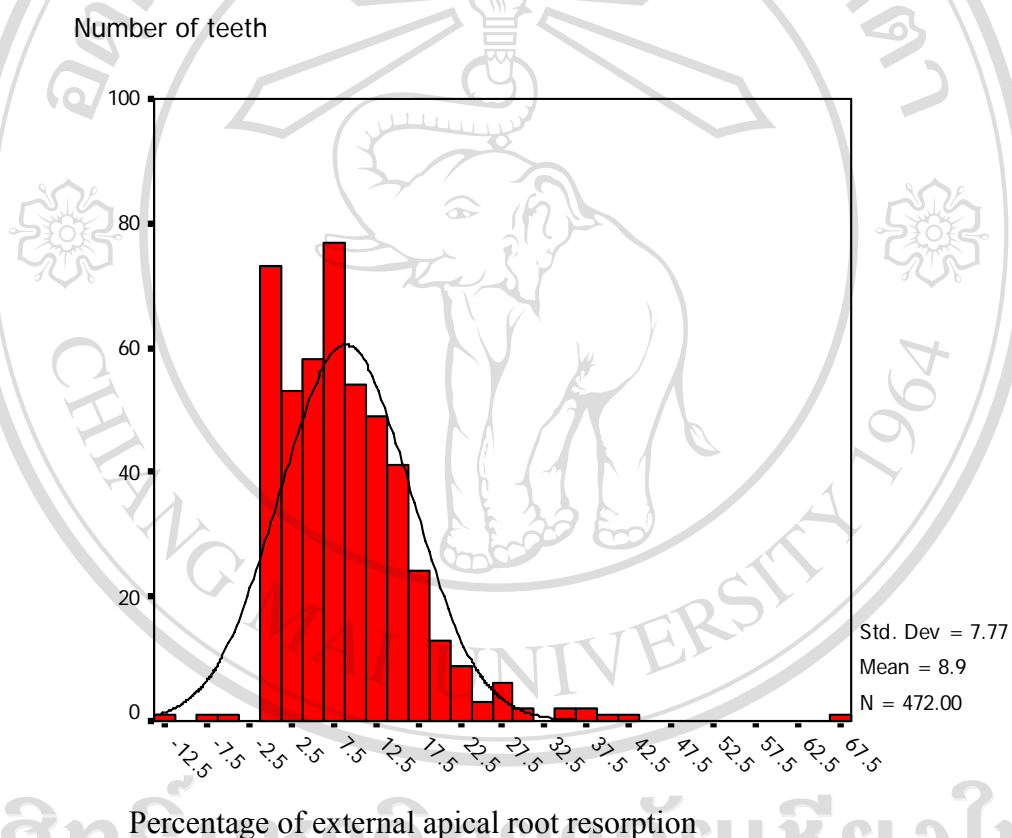
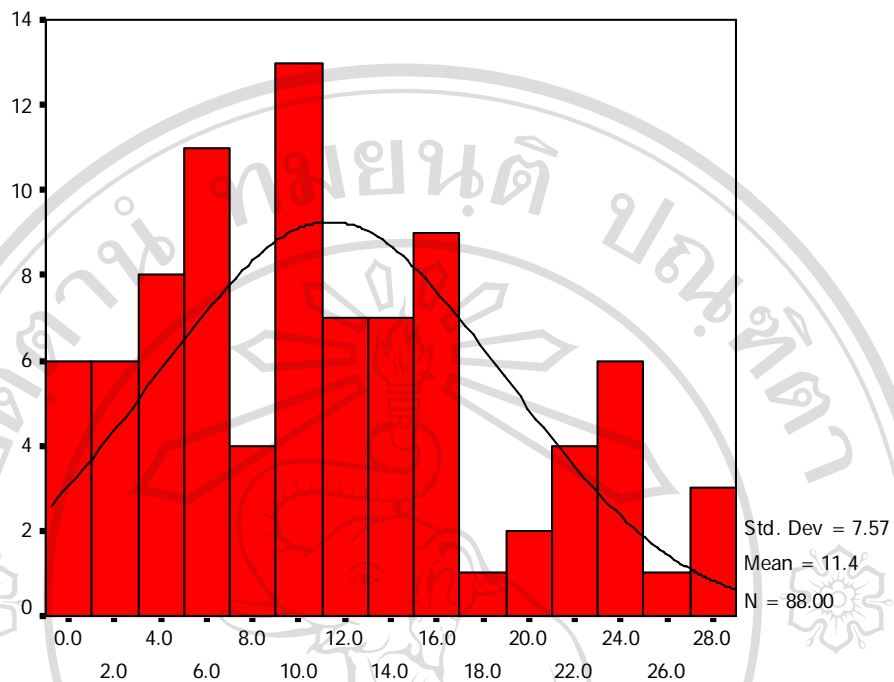


Figure 4.29 Histogram showing percentage of EARR in maxillary incisors in patients without allergic conditions

Number of teeth



Percentage of external apical root resorption

Figure 4.30 Histogram showing percentage of EARR in maxillary incisors in patients with allergic conditions

The minimum amounts of EARR in patients without and with allergic condition were -1.68 and 0.02 mm, respectively. The minimum percentages of EARR per tooth were -11.82% and 0.1%, respectively. The maximum amounts of EARR were 11.72 and 5.04 mm, respectively. The maximum percentages of EARR per tooth were 66.43% and 38.41%, respectively (Table 4.21).

Table 4.21 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in patients with and without allergic conditions

Allergic condition	Without allergic condition		With allergic condition	
	Maximum	Minimum	Maximum	Minimum
Amount of EARR (mm)	11.72	-1.68	5.04	0.02
Percentage of EARR per tooth	66.43	-11.82	28.55	0.1
<i>Number of teeth</i>	472		92	

Although the severest EARR was in the group without allergic conditions, the maximum amount was not a representative value for this group. Therefore, medians and means of amounts and percentages of EARR were calculated. The median amounts of EARR in patients without and with allergic condition were 1.32 and 1.64 mm, respectively. The median percentages of EARR were 7.89% and 10.06%, respectively. The mean amounts of EARR were 1.49 ± 1.30 and 1.81 ± 1.29 mm, respectively. The mean percentages of EARR were $11.36 \pm 7.57\%$ and $8.91 \pm 7.77\%$, respectively. Although, there were slight differences in means and medians of EARR in each group, the distribution of root resorption data were not normal. Therefore, medians were used to find any differences between the two groups. The Mann-Whitney U test showed highly statistically significant differences at $P < .05$ (Table 4.22).

Table 4.22 Medians, interquartile ranges, means and standard deviations of post-treatment EARR in maxillary incisors in patients without and with allergic conditions and their *P*-values (Mann-Whitney U test)

Allergic condition		Without allergic condition	With allergic condition	<i>P</i> -value
Amount of EARR (mm)	Median	1.32	1.64	0.021*
	(Interquartile range)	(1.69)	(1.93)	
	Mean	1.49±1.30	1.81±1.29	
Percentage of EARR per tooth	Median	7.89	10.06	0.003*
	(Interquartile range)	(9.96)	(11.05)	
	Mean	8.91±7.77	11.36±7.57	
<i>Number of teeth</i>		472	92	

* *P* < .05

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- **Types of malocclusion**

Of 181 eligible patients, there were 130 patients who were classified as Angle's Class I occlusion. Thirty-eight other patients demonstrated their occlusion as Angle's Class II. The remaining 13 patients had Angle's Class III occlusion. From those three groups of patients 416, 107 and 41 maxillary incisors, respectively, were included in the statistical investigation.

There was asymmetric distribution of data for percentage of EARR in each type of malocclusion (Figures 4.31, 4.32 and 4.33).

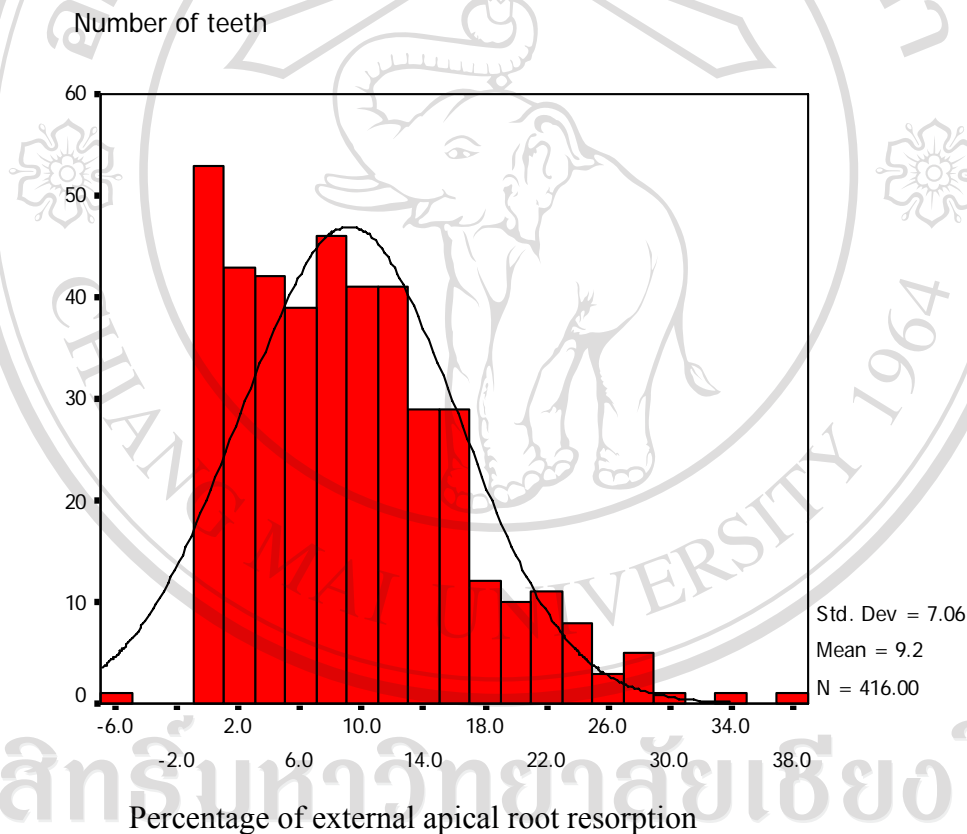
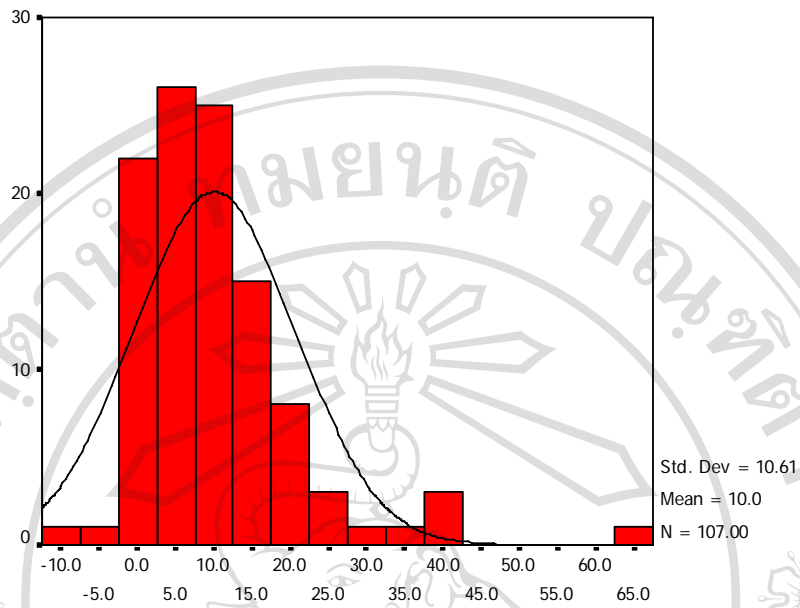


Figure 4.31 Histogram showing percentage of EARR in maxillary incisors in the Class I malocclusion group

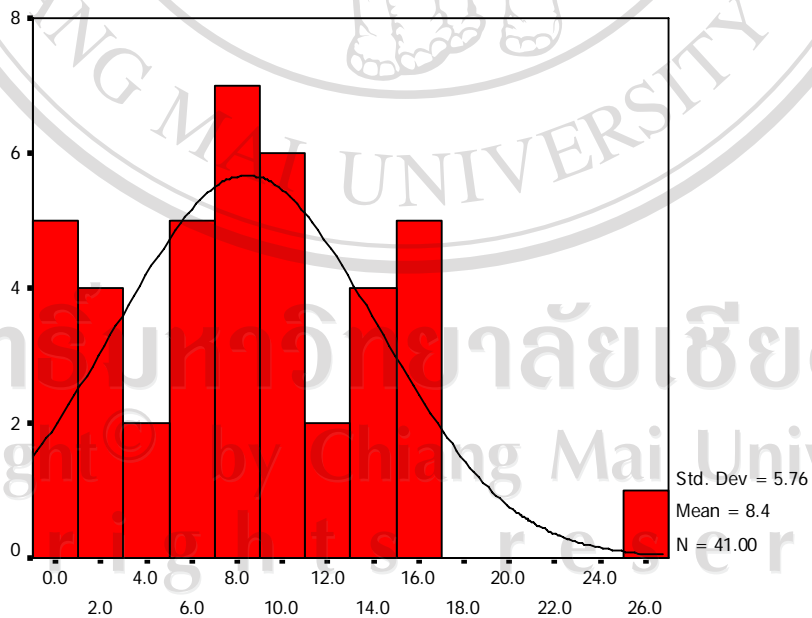
Number of teeth



Percentage of external apical root resorption

Figure 4.32 Histogram showing percentage of EARR in maxillary incisors in the Class II malocclusion group

Number of teeth



Percentage of external apical root resorption

Figure 4.33 Histogram showing percentage of EARR in maxillary incisors in the Class III malocclusion group

The minimum amounts of EARR in each type of malocclusion were -0.91, -1.68 and 0 mm in Angle's Class I, Class II and Class III, respectively. The minimum percentages of EARR per tooth were -6.31, -11.82 and 0.01 per cent, respectively. The maximum amounts of EARR were 5.36, 11.72 and 5.04 mm, respectively. And the maximum percentages of EARR per tooth were 38.41, 66.43 and 26.12 percents, respectively (Table 4.23).

Table 4.23 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in each type of malocclusion

Types of malocclusion	Class I		Class II		Class III	
	Max	Min	Max	Min	Max	Min
Amount of EARR (mm)	5.36	-0.91	11.72	-1.68	5.04	0
Percentage of EARR per tooth	38.41	-6.31	66.43	-11.82	26.12	0.01
<i>Number of teeth</i>	416		107		41	

Besides minimum and maximum values of EARR, medians and means of EARR were calculated as representative data for each group. There were slight differences between medians and means in each malocclusion group. The median amounts of EARR in each type of malocclusion were 1.37, 1.30 and 1.36 mm, respectively. The median percentages of EARR per tooth were 8.08, 8.06 and 8.36 per cent, respectively. The mean amounts of EARR in each type of malocclusion were 1.50 ± 1.15 , 1.73 ± 1.83 and 1.45 ± 1.03 mm, respectively. The mean percentages of EARR per tooth were 9.15 ± 7.06 , 10.04 ± 10.6 and 8.43 ± 5.76 per cent, respectively.

Because the distribution of EARR data in each group was not normal, medians were used to find any differences between the groups. Therefore, the Kruskal-Wallis test was used to compare means of EARR among the three groups of malocclusion. Nevertheless, the statistical calculation did not show any significant differences. Detail of root resorption severity among the three groups is shown in Table 4.24.

Table 4.24 Medians, interquartile ranges, means and standard deviations of post-treatment EARR in maxillary incisors in patients with different Angle's occlusal classifications and their *P*-values (Kruskal Wallis H test)

Types of malocclusion		Class I	Class II	Class III	<i>P</i> -value
Amount of EARR (mm)	Median	1.37	1.30	1.36	0.94
	(Interquartile range)	(1.64)	(1.95)	(1.44)	
	Mean	1.50±1.15	1.73±1.83	1.45±1.03	
Percentage of EARR per tooth	Median	8.08	8.06	8.36	0.946
	(Interquartile range)	(10.10)	(10.90)	(8.78)	
	Mean	9.15±7.06	10.04±10.6	8.43±5.76	
<i>Number of teeth</i>		416	107	41	

• **Treatment planning (Non-extraction/Extraction)**

Patients who had no upper premolar teeth extracted were included in the non-extraction group. Those that had at least one upper premolar tooth extracted were included in the extraction group. There were 130 patients who had upper first or second premolar teeth extracted to gain space during the course of orthodontic treatment. Four hundred and five incisor teeth in patients who complied with the criteria of selection were selected for comparison with 159 teeth from 50 patients who had no upper premolars extracted.

Therefore, 159 and 405 teeth were included in non-extraction and extraction groups, respectively. Their distribution of data for percentage of EARR in maxillary incisors in non-extraction and extraction group showed asymmetric distribution (Figures 4.34 and 4.35).

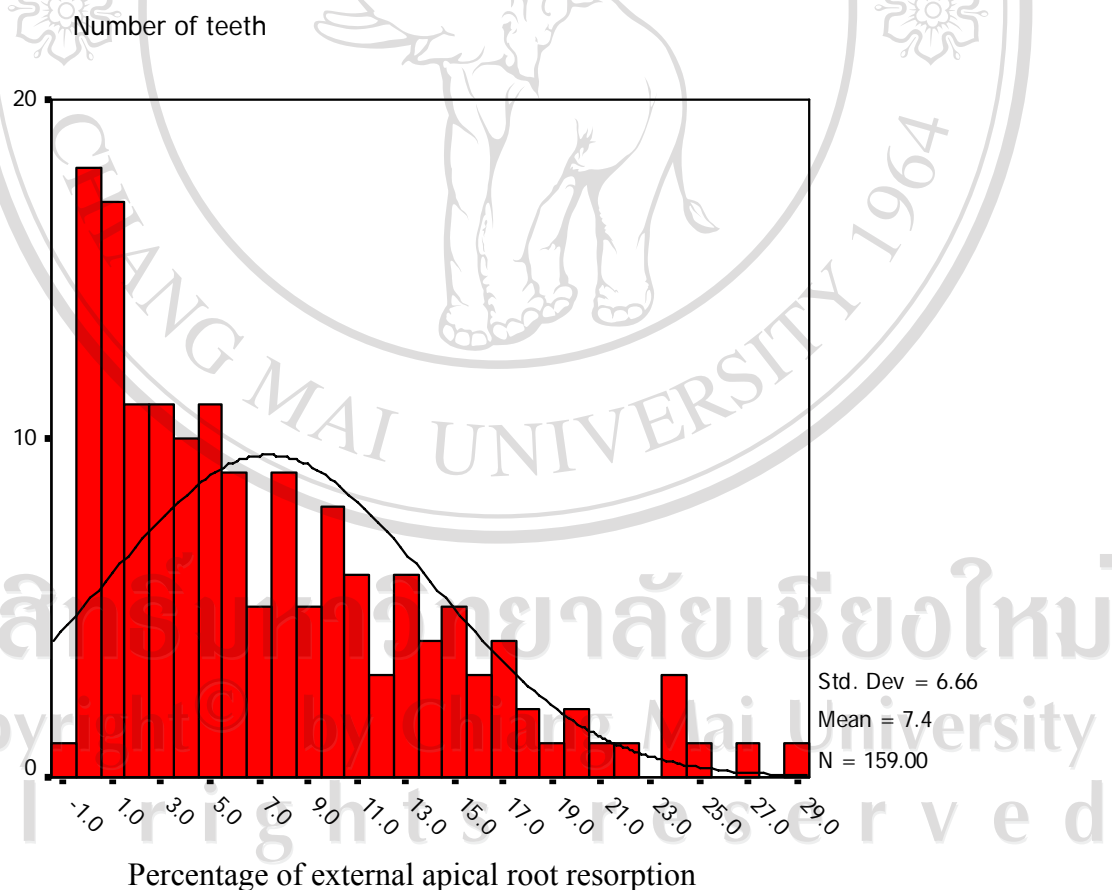


Figure 4.34 Histogram showing percentage of EARR in maxillary incisors in the non-extraction group

Number of teeth

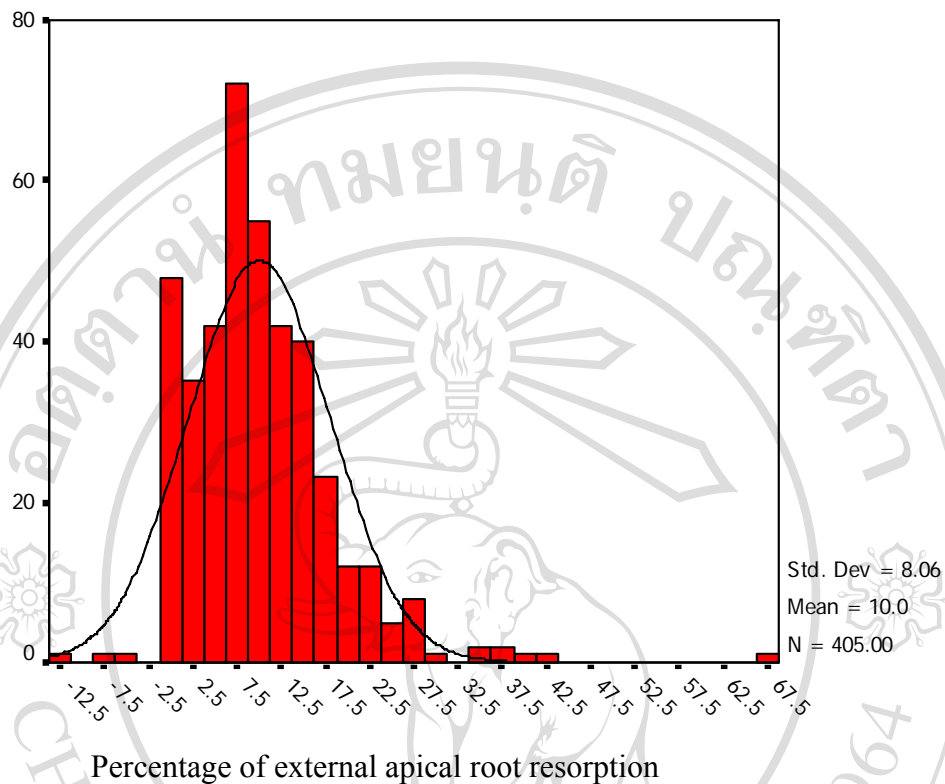


Figure 4.35 Histogram showing percentage of EARR in maxillary incisors in the extraction group

The minimum amounts of EARR in non-extraction and extraction groups were -0.1 and -0.168 mm, respectively. The minimum percentage of EARR per tooth was -0.54 and -11.82 percents. The maximum amount of EARR was 4.34 and 11.72 mm. And the maximum percentage of EARR per tooth was 29.13 and 66.43 percents, respectively (Table 4.25).

Table 4.25 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in the non-extraction and extraction groups

Treatment planning	Non-extraction		Extraction	
	Maximum	Minimum	Maximum	Minimum
Amount of EARR (mm)	4.34	-0.1	11.72	-1.68
Percentage of EARR per tooth	29.13	-0.54	66.43	-11.82
<i>Number of teeth</i>	159		405	

Medians and means were calculated to represent the EARR data in each group. The median amounts of EARR in patients in the non-extraction and extraction groups were 0.92 and 1.47 mm, respectively. The median percentages of EARR per tooth were 5.57% and 8.94%, respectively. The mean amounts of EARR were 1.19 ± 1.07 and 1.68 ± 1.34 mm, respectively. The mean percentages of EARR per tooth were $7.36 \pm 6.66\%$ and $10.02 \pm 8.06\%$, respectively.

However, medians were used to find any differences between non-extraction and extraction groups because of asymmetric distribution of root resorption data in each group. The Mann-Whitney U test showed that the upper premolar extraction group had highly statistically significant factors for EARR at $P < .001$. The medians and means of EARR in millimeters and the percentages of EARR per tooth in both non-extraction and extraction groups and their significance values are shown in Table 4.26.

Table 4.26 Medians, interquartile ranges, means and standard deviations of post-treatment EARR in maxillary incisors in non-extraction and extraction groups and their *P*-values (Mann-Whitney U test)

Treatment planning		Non-extraction	Extraction	<i>P</i> -value
Amount of EARR (mm)	Median	0.92	1.47	< 0.001 ***
	(Interquartile range)	(1.66)	(1.62)	
	Mean	1.19±1.07	1.68±1.34	
Percentage of EARR per tooth	Median	5.57	8.94	< 0.001 ***
	(Interquartile range)	(9.85)	(9.57)	
	Mean	7.36±6.66	10.02±8.06	
<i>Number of teeth</i>		159	405	

*** *P* < .001

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- **Types of bracket**

There were 66 and 111 patients who were treated with standard or pre-adjusted brackets, respectively. Two hundred and thirty seven and 327 maxillary incisor teeth, in patients in whom standard and pre-adjusted brackets, respectively, were used, were investigated.

There were asymmetric distributions of data for percentage of EARR in maxillary incisors in patients treated with standard and pre-adjusted brackets (Figure 4.36 and 4.37).

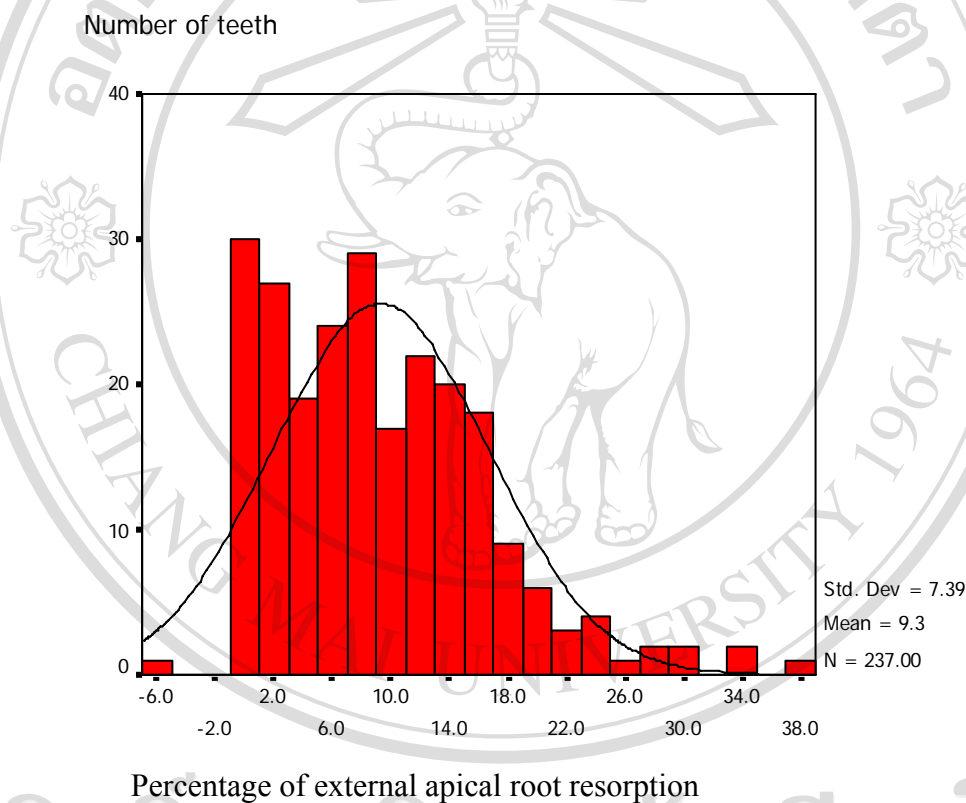
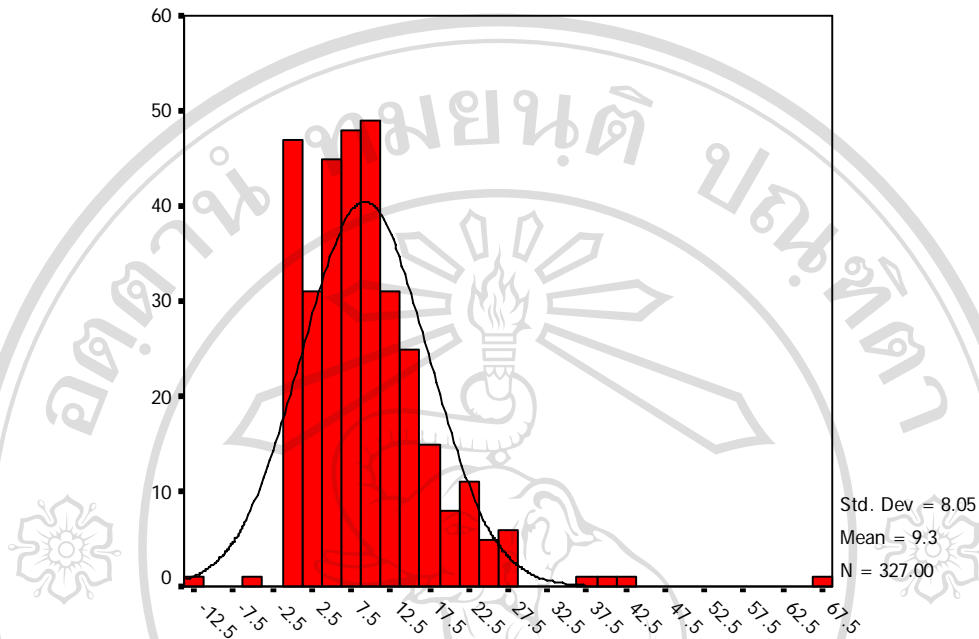


Figure 4.36 Histogram showing percentage of EARR in maxillary incisors in patients treated with standard brackets

Number of teeth



Percentage of external apical root resorption

Figure 4.37 Histogram showing percentage of EARR in maxillary incisors in patients treated with pre-adjusted brackets

The minimum amounts of EARR in patients treated with standard or pre-adjusted brackets were -0.91 and -1.68 mm, respectively. The minimum percentages of EARR per tooth were -6.31% and -11.82%, respectively. The maximum amounts of EARR were 5.18 and 11.72 mm, respectively. And the maximum percentages of EARR per tooth were 38.41% and 66.43%, respectively (Table 4.27).

Table 4.27 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in patients treated with standard or pre-adjusted brackets

Types of bracket	Standard bracket		Pre-adjusted bracket	
	Maximum	Minimum	Maximum	Minimum
Amount of EARR (mm)	5.18	-0.91	11.72	-1.68
Percentage of EARR per tooth	38.41	-6.31	66.43	-11.82
<i>Number of teeth</i>	237		327	

There were slight differences in means and medians of EARR in each group. Median amounts of EARR and median percentages of EARR per tooth were 1.33 mm (8.07%) and 1.37 mm (8.22%) in standard bracket and pre-adjusted groups, respectively. The mean amounts and mean percentages of EARR per tooth were 1.50 mm (9.28%) and 1.57 mm (9.25%) in patients who were treated with standard and pre-adjusted brackets, respectively.

The distributions of root resorption data in each bracket group were not normal; therefore, medians were used to find any differences between groups. However, there was no statistically significant difference in EARR between the teeth treated with standard or pre-adjusted brackets at $P < .05$ (Table 4.28).

Table 4.28 Medians, interquartile ranges, means and standard deviations of post-treatment EARR in maxillary incisors treated by standard or pre-adjusted brackets and their *P*-values (Mann-Whitney U test)

Type of bracket		Standard bracket	Pre-adjusted bracket	<i>P</i> -value
Amount of EARR (mm)	Median	1.33	1.37	0.927
	(Interquartile range)	(1.73)	(1.61)	
	Mean	1.50±1.15	1.57±1.40	
Percentage of EARR per tooth	Median	8.07	8.22	0.748
	(Interquartile range)	(10.71)	(9.35)	
	Mean	9.28±7.39	9.25±8.05	
<i>Number of teeth</i>		237	327	

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- **Treatment duration**

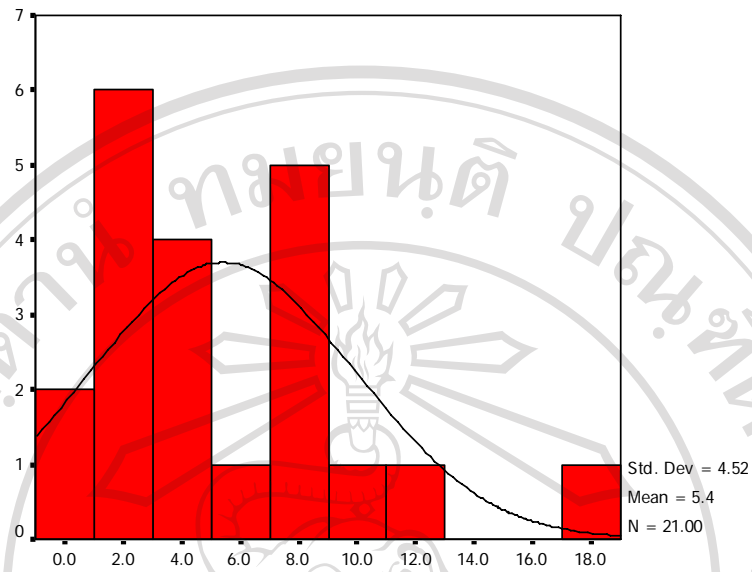
In the investigated records, mean treatment duration was 28.91 ± 9.50 months. It ranged from 8 to 58 months. Of 181 patients, there were only 6 patients who finished their course of orthodontic treatment within one year. There were 47, 90 and 38 patients who took 2, 3 or more than 3 years, respectively, for a complete course of orthodontic treatment. Twenty-one, 154, 237 and 116 teeth in patients who complied with the criteria of selection were included in the 1-, 2-, 3- and more than 3-year treatment groups, respectively (Table 4.29).

Table 4.29 Numbers of patients who completed orthodontic treatment within 1, 2, 3 or more than 3 years

Treatment duration	1-12 months (1 year)	13-24 months (2 years)	25-36 months (3 years)	>36 months (>3 years)
Number of patients	6	47	90	38
Number of teeth	21	154	237	116
Percentage	3.3	26	49.7	21

In each treatment duration group, the distributions of data for percentage of EARR were not normal (Figures 4.38, 4.39, 4.40 and 4.41).

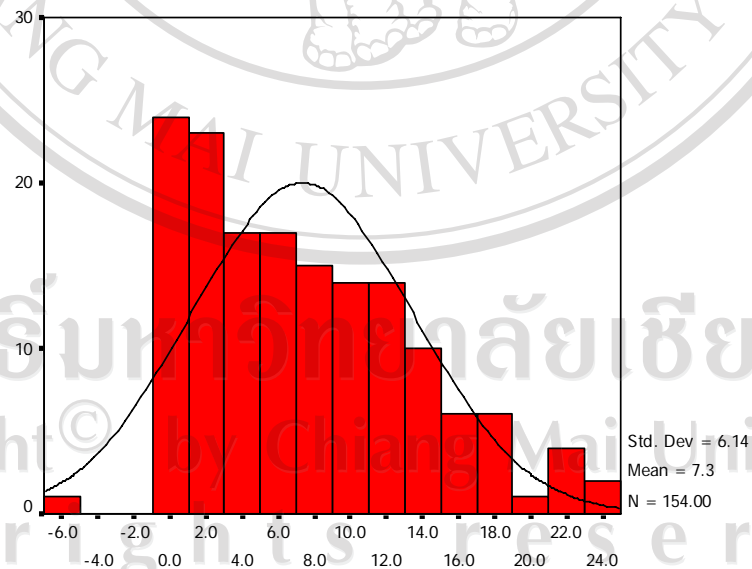
Number of teeth



Percentage of external apical root resorption

Figure 4.38 Histogram showing percentage of EARR in maxillary incisors in patients in the 1-year group

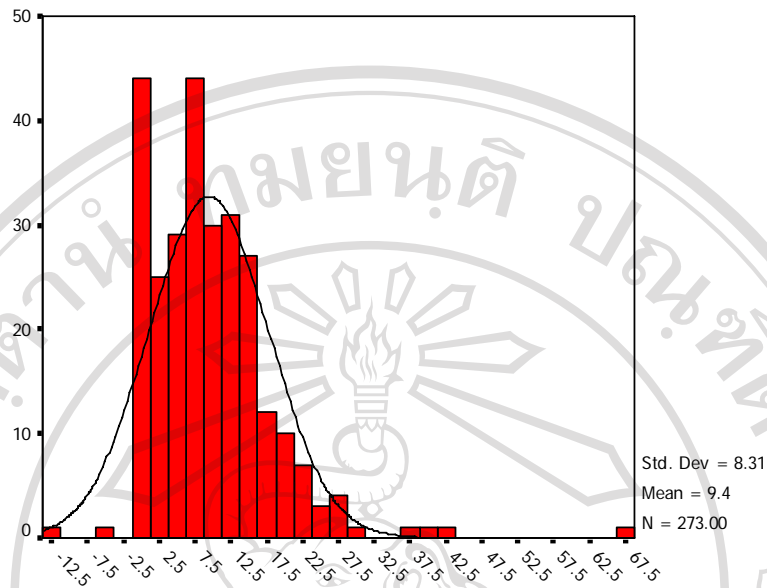
Number of teeth



Percentage of external apical root resorption

Figure 4.39 Histogram showing percentage of EARR in maxillary incisors in patients in the 2-year group

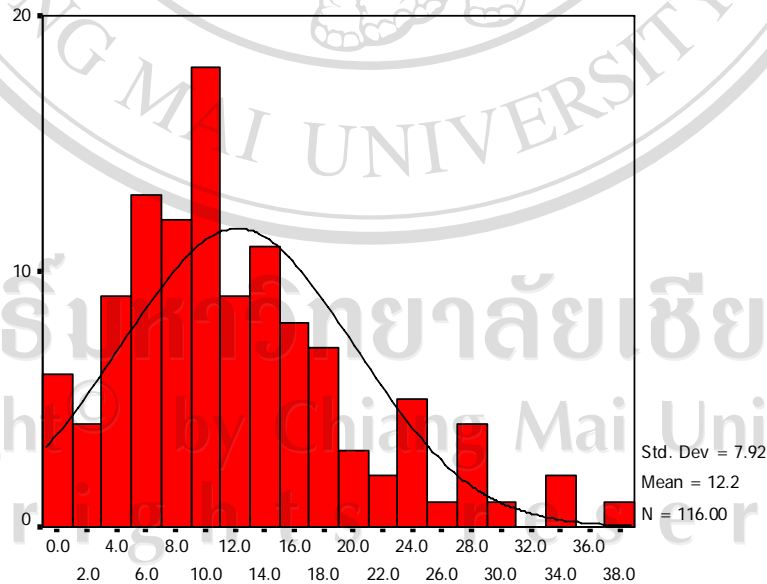
Number of teeth



Percentage of external apical root resorption

Figure 4.40 Histogram showing percentage of EARR in maxillary incisors in patients in the 3-year group

Number of teeth



Percentage of external apical root resorption

Figure 4.41 Histogram showing percentage of EARR in maxillary incisors in patients in the more than 3-year group

Treatment duration was divided into ranges; within 1, 2, 3 and more than 3 years. The minimum amounts of EARR in each treatment duration group were 0.08, -0.91, -1.68 and 0 mm, respectively. The minimum percentages of EARR per tooth were 0.26, -6.13, -11.82 and 0.01 per cent, respectively. The maximum amounts of EARR were 2.99, 4.27, 11.72 and 5.24 mm, respectively. And the maximum percentages of EARR per tooth were 18.23, 24.51, 66.43 and 38.41 per cent, respectively (Table 4.30).

Table 4.30 Maximum and minimum amounts of EARR and percentages of EARR per tooth in maxillary incisors in each treatment duration group

Treatment duration	1-12 months (1 year)		13-24 months (2 years)		25-36 months (3 years)		>36 months (>3 years)	
	Max	Min	Max	Min	Max	Min	Max	Min
Amount of EARR (mm)	2.99	0.08	4.27	-0.91	11.7	-1.68	5.24	0
Percentage of EARR per tooth	18.23	0.26	24.5	-6.31	66.4	-11.8	38.4	0.01
<i>Number of teeth</i>	21		154		173		116	

However, the maximum values were not representative for comparing the EARR in each group. Therefore, medians and means of EARR was calculated to represent the values of EARR in each group. The median amounts of EARR in each group were 0.83, 1.01, 1.41 and 1.73 mm, respectively. Median percentages of EARR per tooth were 6.21, 8.42, 8.57 and 10.49 per cent, respectively. The mean amounts of EARR in each group were 0.94 ± 0.76 , 1.23 ± 1.05 , 1.61 ± 1.42 and 1.91 ± 1.25 mm, respectively. Mean percentages of EARR per tooth were 5.41 ± 4.52 , 7.33 ± 6.14 , 9.42 ± 8.31 and 12.18 ± 7.92 per cent, respectively.

Medians and means, were almost similar in each treatment duration group. However, medians were used to find any differences between groups. The results showed that the longer the treatment duration, the more EARR. The Kruskal-Wallis calculation showed highly statistically significant differences in means of EARR between each treatment duration group, $P < .001$ (Table 4.31).

Table 4.31 Medians, interquartile ranges, means and standard deviations of EARR in maxillary incisors in patients with various ranges of treatment duration (Kruskal-Wallis H calculation)

Treatment duration		1-12 months (1 year)	13-24 months (2 years)	25-36 months (3 years)	>36 months (>3 years)	<i>P</i> -value
Amount EARR (mm)	Median	0.83	1.01	1.41	1.73	< 0.001***
	(Interquartile range)	(1.09)	(1.60)	(1.67)	(1.64)	
	Mean	0.94±0.76	1.23±1.05	1.61±1.42	1.91±1.25	
Percentage of EARR per tooth	Median	6.21	8.42	8.57	10.49	< 0.001***
	(Interquartile range)	(6.61)	(9.18)	(10.59)	(10.13)	
	Mean	5.41±4.52	7.33±6.14	9.42±8.31	12.18±7.92	
<i>Number of teeth</i>		21	154	273	116	

*** *P* < .001