

Key Factors Contributing to The Anchorage Loss of Maxillary First Molars: A Retrospective Study of 726 Extraction Cases

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Abstract

Background: Anchorage control is one of the key components in the treatment of extraction cases. However, why anchorage loss happens is still an unanswered question. The purpose of this study was to investigate the most important factors contributing to the anchorage loss of maxillary first molars in premolar extraction cases. The study enrolled 726 upper premolar extraction cases, including 214 male patients and 512 female patients, and the average age was 14 (range: 9-45 years old). Factors including physiological characteristics, treatment mechanics and cephalometric variables were collected and their influences on the angulation changes of maxillary first molars were analyzed.

Results: The average angulation change of maxillary first molar after treatment was 2.81° , meaning the molar tipped forward during treatment by 2.81° . The change of UM/PP showed statistically significant difference in different sex (male $3.84^\circ \pm 5.26^\circ$ vs female $2.38^\circ \pm 5.10^\circ$), age (adult $-0.05^\circ \pm 4.73^\circ$ vs teenager $3.46^\circ \pm 5.07^\circ$), and molar relationship (Class II $3.28^\circ \pm 5.15^\circ$ vs Class I $2.36^\circ \pm 5.19^\circ$). There are six variables accounted in the regression analysis ($R=0.608$, $R^2=37.0\%$). Among them, the pre-treatment molar tipping (Standardized Coefficients -0.65) and the pre-treatment incisor/molar height ratio (Standardized Coefficients -0.27) were the most important factors influencing anchorage loss during treatment.

Conclusion: Compared with treatment-related factors, the patient's physiological characteristics play a more important role in anchorage loss. The pre-treatment angulation of the maxillary first molar is the most contributing factor of the maxillary molar angulation changes, which are often predisposing anchorage loss.

Background

It is not uncommon to treat orthodontic patients with extractions, which requires thorough treatment planning and accurate diagnosis. Among all the considerations regarding extraction, anchorage control is one of the key components. For orthodontists, it's always imperative to choose proper mechanics to prevent molars from unfavorable mesialization. For decades, orthodontists have been designing a variety of intraoral or extraoral appliances to preserve anchorage, such as Nance palatal arch [1], lower lingual arch [2], transpalatal arch [3], headgear [4], and TADs [5–7], etc. There are plenty of studies evaluating those appliances, and the amount of molar movement plays a key role and has become one of the most important standards.

A common undesirable outcome of anchorage loss is the excessive molar mesialization along with molar mesial tipping, which occupies the space reserved for the retraction of incisors. Studies [8, 9] have shown that the mesial tipping almost always accompanies mesialization during orthodontic treatment. For cases requiring maximum anchorage, molar tipping can occupy extraction space and result in anchorage loss; in some cases, tipping may change the occlusal plane, which in turn negatively affects treatment outcome and stability. On the contrary, an arguably better option is distal tipping; many treatment

philosophies incorporate distal bends to the archwire to counter the mesial tipping of molars, such as the classic edgewire technique[10, 11]and Begg technique[12]. Tweed techniqueapplies a considerable amount of distal molar tipping for anchorage preservation. Research studying anteroposterior discrepancy emphasized linear molar movement; however, few studies focused on studying the tipping movement of molars.

Another phenomenon that haunts orthodontists is the various treatment responses to the same treatment technique, regardless of the type of appliances they have used [13]. As a matter of fact, maxillary first molars stay relatively stable for some patients and it mesializes and tips forward rapidly in the very beginning for another group of patients. Even though orthodontists make great efforts to differentiate patients who are prone to anchorage loss and those who are not, few successes have been achieved. A variety of research studies different types of appliances or treatment mechanics that are capable of reinforcing anchorage; however, few studies focus on the physiological characteristics of patients to predict anchorage loss. Consequently, it is not clear what elements really contribute to anchorage loss.

This study is a retrospective cross-sectional study that focuses on the angular change of the maxillary first molar with maxillary premolar extraction cases with Class I or Class II malocclusion that requires moderate or strict anchorage control. By studying the maxillary molar tipping, we hope to find out related physiological characteristics that can help predict anchorage loss during orthodontic treatment.

Material And Methods

The sample was collected from the patients who finished their treatment during 1997-2005 at the Orthodontic department of Peking University School and Hospital of Stomatology. The inclusion criteria include: 1. Angle class I or class II patients; 2. Extraction of two maxillary premolars; 3. Completion of treatment with straight appliance; 4. Complete treatment records; 5. Presence of maxillary first molars pre and post-treatment;6. Uncompromised cephalometric X-rays taken by the same machine. The exclusion criteria include: 1. Retreatment cases; 2. Non-fixed appliances; 3. Surgical patients. The sample consisted of 726 cases with 214 male patients (29.5%) and 512 female patients (70.5%), and the average age is 14.4years old with a range of 9-45 years old. There were 135 adult patients (18.6%) and 375 teenagers (81.4%), and 48.6% of them had Class II malocclusion (353). We analyzed physiological characteristics, types of malocclusion, treatment mechanics, time in leveling and alignment, and total treatment time.

The dataset was measured and collected by five orthodontic PhD students, including treatment records and cephalograms. The variables involved in this study include:

1. Variables regarding treatment records:
 - a. Physiological variables: age, sex, Angle classification, deep overbite, deep overjet, open bite, scissor bite, and the amount of maxillary crowding.
 - b. Treatment mechanics: usage of bite plate, occlusal splint, pendulum appliance, transpalatal arch, Nance appliance, headgear, and maxillary expansion.

2. Variables from cephalograms: All cephalograms were taken by the radiology department at Peking University School and Hospital of Stomatology. After scanning and uploading the cephalograms onto the computer, three orthodontic PhD students located digital landmarks. Software was used for landmark location and cephalometric measurements
3. The dependent variable of this study is the angular change of the maxillary first molars relative to palatal plane. The tooth axis of the first molar is defined as the line connecting the mesial buccal cusp and the mesial buccal apex of the first molar. UM/PP is defined as the angle formed by the molar axis and palatal plane (Fig 1). The cephalometric measurements include pre-treatment (1), changes during treatment (2), and post-treatment (3). UM/PP-12 is the abbreviation of the independent variable. Fig 2 shows the landmarks, and Table 1 lists the cephalometric measurements and the corresponding definition.

Table 1. Cephalometric measurements and the corresponding definition

Variables	Name	Definition
UM/PP [°]	Maxillary molar tipping	The angle formed by the molar axis and palatal plane
SNA [°]	SNA	The angle formed by Sella – Nasion and Nasion – A-point
SNB [°]	SNB	The angle formed by Sella – Nasion and Nasion – B-point
ANB [°]	ANB	The subtraction of SNB from SNA
MP/SN [°]	Mandibular plane	The angle formed by Sella – Nasion and mandibular plane
UI/PP [°]	Maxillary incisal tipping	The angle formed by incisal axis (incisal edge to incisal apex) and palatal plane
UIE-PP ^{mm}	Maxillary incisor to PP	The vertical distance between the edge of maxillary incisors and palatal plane
UMC-PP ^{mm}	Maxillary molar to PP	The vertical distance between the mesial buccal cusp of maxillary molars and palatal plane
UIE-PP/UMC-PP	Incisor/molar height ratio	The ratio of the vertical position of incisor to that of molar

Statistical analysis:

The whole dataset was analyzed via SPSS v16.0 (SPSS, Chicago, IL, USA). The significance level was set at $p < 0.05$. Independent T-test and stepwise linear regression were used. Multiple regression analysis was performed to study the relation between molar tipping and other variables.

Results

1. UM/PP-12 and patients' physiological characteristics

The average maxillary first molar tipping was 2.81° for the CL I and CL II patients, meaning the molar tipped forward during treatment. The outcome of the t-test regarding the change of UM/PP and physiological characteristics were shown in Table 2; sex (male 3.84° vs female 2.38°), age (adult -0.05° vs teenager 3.46°), and molar relationship (CL II 3.28° vs CL I 2.36°) showed statistically significant difference. Male teenagers with CL II malocclusion exhibited more mesial tipping of the maxillary molars. It was worth noting that the molar tipping on adult patients is close to 0°, indicating the molars of adult patients underwent bodily movement or minimum anchorage loss.

Table 2. The relation of the change of maxillary molar angulation and physiological characteristics

Independent variables		Sample size	UM/PP-12		
			Average	Standard deviation	P-value
Sex	male	214	3.84	5.26	0.000**
	female	512	2.38	5.10	
Age	teenager	591	3.46	5.07	0.000**
	adult	135	-0.05	4.73	
Deep overjet	no	234	2.80	5.37	0.983
	yes	492	2.81	5.11	
Deep overbite	no	230	2.41	4.97	0.159
	yes	496	2.99	5.28	
Open bite	no	710	2.82	5.21	0.765
	yes	16	2.42	4.20	
Maxillary crowding	no	129	2.01	5.19	0.053
	yes	597	2.98	5.18	
Scissors bite	no	655	2.80	5.25	0.889
	yes	71	2.89	4.59	
Molar relationship	I	373	2.36	5.19	0.018*
	II	353	3.28	5.15	

*: P < 0.05; **: P < 0.01.

2. UM/PP-12 and treatment mechanics

The relation of UM/PP and treatment mechanics was shown in table 3. As far as the mechanics were concerned, it did not have any statistically significant effect on the maxillary molar tipping.

Table 3. The outcome of t-test regarding UM/PP-12 and treatment mechanics

Treatment-related variables	Application	Sample size	UM/PP-12		P-value
			Average	Standard deviation	
Bonding of second molars	no	586	2.88	5.14	0.436
	yes	140	2.50	5.41	
Bite plate	no	689	2.81	5.20	0.916
	yes	37	2.72	5.10	
Occlusal splint	no	714	2.80	5.22	0.903
	yes	12	2.99	3.19	
Pendulum appliance	no	723	2.81	5.18	0.610
	yes	3	1.28	7.54	
TPA	no	619	2.95	5.28	0.072
	yes	107	1.97	4.56	
Nance appliance	no	659	2.73	5.20	0.226
	yes	67	3.54	5.10	
Headgear	no	515	2.87	5.10	0.617
	yes	211	2.66	5.42	
Maxillary expansion	no	713	2.82	5.19	0.578
	yes	13	2.01	5.17	

*: $P < 0.05$; **: $P < 0.01$

3. Stepwise multiple regression analysis

The independent variables were listed in table 4. To better evaluate the effect of different variables in relation to maxillary molar tipping, we selected the statistically significant variables in table 2 and 3 and all the variables in table 4. The regression analysis was performed with the above-mentioned variables as independent variables and UM/PP-12 as dependent variables. The result was shown in table 5.

Table 4. Cephalometric and time-related variables

Variables	Average	Standard deviation
ANB-1 (°)	5.25	2.16
SNA-1 (°)	82.37	3.34
SNB-1 (°)	77.16	3.51
MP/SN-1 (°)	38.18	5.86
UI/PP-1 (°)	120.17	7.57
UIE-PP-1 (mm)	31.83	2.83
UM/PP-1 (°)	79.43	5.74
UMC-PP-1 (mm)	24.93	2.72
UIE-PP/UMC-PP-1 (ratio)	1.28	0.10
Time in NiTi wire(month)	8.85	4.77
Total treatment time□month□	30.07	10.00

Table 5. The outcome of stepwise multiple regression analysis

	Unstandardized coefficients		Standardized Coefficients	t	P-value
	B	Std. Error	Beta		
(Constant)	78.98	5.53		14.29	0.000
UM/PP-1	-0.59	0.04	-0.65	-16.60	0.000
UIE-PP/UMC-PP-1	-13.42	2.11	-0.27	-6.36	0.000
UMC-PP-1	-0.35	0.08	-0.19	-4.65	0.000
Sex	-1.46	0.35	-0.13	-4.15	0.000
ANB-1	-0.29	0.08	-0.12	-3.55	0.000
Angle classification	-0.72	0.34	-0.07	-2.09	0.037

According to table 5, there were six variables accounted in the regression analysis ($R=0.608$, $R^2=37.0\%$, $R^2_{adj}=36.3\%$). Among them, the pre-treatment molar tipping (UM/PP-1, Standardized Coefficients=-0.65)

was the most contributing factor, followed by the pre-treatment incisor/molar height ratio (UIE-PP/UMC-PP-1, Standardized Coefficients=-0.27)

Discussion

One of the key components of orthodontic treatment is anchorage control. Many studies focused on linear change instead of on tipping movement of molars [14,15]; however, during orthodontic treatment, crown movement surpasses root movement in speed and extent, signifying the initiation of anchorage loss. Molar mesialization almost always accompanies forward tipping, in other words, mesial tipping is closely related to anchorage loss. Unfortunately, orthodontists rarely take naturally or physiologically tipping of molars into consideration while developing a treatment plan. This cross-sectional study comprehensively analyzed physiological factors and mechanical factors that might trigger anchorage loss, in Class I or Class II patients who underwent extraction and required anchorage control. A few characteristics have been found that are attributable to anchorage loss and we believe that more attention should be given to preserving anchorage on patients who have those signs.

Growth (age) plays an important role in the anchorage loss of upper first molar. The majority of orthodontic patients are teenagers. According to table 2, teenagers exhibited 3.46° mesial tipping of the maxillary first molar while adults 0.05° distal tipping, and it showed statistical significance. The results agree with the finding in Xu's study [13], which showed younger adolescents had significantly more molar mesial displacement than older adolescents (mean difference, 1.3 mm). McKinney [16] also found similar results that showed teenagers are prone to anchorage loss more than adults. It is reasonable because teenager is a period around the second growth peak, during which the maxillary first molar will tip forward significantly by growth. Plenty of longitudinal studies reported gradual mesial tipping during this period. Iseri and Solow [17] noticed the maxillary first molar would continuously erupt inferiorly and anteriorly before 25 years old and it would continue erupting with a slower speed afterward. Tsourakis and Johnston [18] found out a compensatory growth pattern of the maxillary molars in response to the greater and longer mandibular growth, which revealed a close relation between the movement of maxillary molar and mandibular growth. Zhang [19] studied the longitudinal eruptive and post-eruptive tooth movements using oblique and lateral cephalograms with implants. They found that continuous mesial tipping of the maxillary molars happened from 8.5 to 16 years of age, averaging $8.2^\circ \pm 5.5^\circ$ for the first molars and $18.3^\circ \pm 8.5^\circ$ for the second molars. Therefore, we inferred that the anchorage loss before adulthood might spring from two factors: 1. The application of force during space closure; 2. Growth and development of maxillary teeth, the direction of which is down and forward.

According to table 2, sex is obviously another factor contributing to maxillary molar tipping during orthodontic treatment. Male patients tend to undergo more mesial tipping than female patients do, which is in agreement with previous studies [13,16]. We believe this phenomenon is attributable to the relatively late arrival of the male growth peak. With similar height, female patients are in average two years in advance in terms of maturation, while male patients grow later and greater.

According to table 2, the maxillary first molar tipped forward greater in Class II patients, indicating Class II patients are predisposed to anchorage loss. Our previous cross-sectional study [20] found that patients with Class II malocclusion had the most distally tipped UMs. Kim [21] stated a well-compensated Class II patient tended to exhibit the most distal tipping of the maxillary first molars. For Class patients, the distally-tipped maxillary molars would be leveled and aligned in the very beginning by a flat light wire, causing unfavorable anchorage loss, and reduced extraction space. McKinney [16] mentioned the undesirable anchorage loss with the straight-wire brackets, which should be considered iatrogenic and unnecessary.

In order to stop the upper first molar from tipping forward, orthodontists resort to auxiliary appliances (Nance appliance, TPA, and headgear, etc.). However, our results showed that different types of auxiliary appliances used in this study had no statistically significant effect on the angular change of maxillary first molar (table 3). We guess that the flat wires engaged in the upper arch would do the leveling 24 hour a day throughout the whole treatment, while headgears are worn 8-12hour per day. Nance appliance and TPA could reduce the angular change of maxillary first molar.

To compare various factors in regards to the amount of maxillary molar tipping, stepwise multiple regression analysis was performed. According to the result from table 5, the most contributing factor to the regression formula was the pre-treatment angulation of the maxillary first molars. Since the pre-treatment status of molars is determined completely by individual malocclusion and physiological characteristics, and its role is strikingly more important than the traditionally-believed forces from space closure or other mechanics. The negative standardized coefficients suggested that the more the distal tipping of pre-treatment maxillary first molars, the more the mesial tipping would occur during orthodontic treatment, in other words, the more the anchorage loss would happen.

From table 5, the second most contributing factor was the incisor/molar height ratio (the ratio of the vertical position of incisor to that of molar relative to the palatal plane). The negative standardized coefficients indicated the less the pre-treatment UIE-PP/UMC-PP-1, the more the mesial tipping of the maxillary first molars. The different relative heights of the brackets' position resulted in different deformities of the wires. The incisor/molar height ratio is rarely mentioned and considered in other studies, but it could be an important indicator of anchorage loss.

Limitations

The present study has some limitations. There were more female and teenager patients, and in most of the case, the extracted teeth were upper first premolars, which might bring systematical bias into the study. These limitations were due to the availability of data.

In summary, this study is a supplement of the traditionally-believed concept that anchorage loss is merely from the mechanical force used during space closure, and it brings about something new into consideration. We believe the natural compensatory eruption of maxillary molars relative to mandibular growth, as a natural physiological characteristic of the dentoalveolar growth, plays an imperative role in

anchorage control. The results of this study show various patient's responses to the Straight Wire Appliance. For extraction cases with the need for anchorage control, anchorage loss tends to occur in specific groups of patients, like teenager, male, and Class II. When it comes to pretreatment distally-tipped maxillary molars, this status is a type of anchorage preservation. Although the Straight Wire Appliance is renowned for its convenience, it is worth considering how to avoid iatrogenic maxillary molar tipping caused by the insertion of a NiTi wire in the molar tube.

Conclusion

1. Maxillary first molars tend to tip mesially during orthodontic treatment combined with maxillary premolar extraction. It should be regarded as a type of anchorage loss and therefore be paid attention to. Compared with treatment-related factors, the patient's own physiological characteristics play a more important role in the maxillary molar tipping. The pre-treatment angulation of the maxillary first molar is the most contributing factor of the anchorage loss: the more the pre-treatment distal tipping, the more the mesial tipping during treatment.
2. For the Class I and Class II extraction patients, maxillary mesial tipping tends to occur in the specific groups of patients, like teenager, male, and Class II. Orthodontists should pay attention to and take action on the iatrogenic anchorage loss.

Abbreviations

UM/PP: The angle formed by the molar axis and palatal plane; TADs: Temporary Anchorage.

Declarations

Acknowledgments

Not applicable

Authors' contributions

H.S. and K.Y.X. contributed to data analysis and wrote the main manuscript text. B.H. contributed to data acquisition and analysis. G.C. contributed to result interpretation, figures 1 and 2 preparation, and revising manuscript critically. T.M.X. contributed to design and gave final approval of the version to be published and agreed to be accountable for all aspect of the work. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The present study was approved by the Ethics Committee of Peking University School and Hospital of Stomatology (PKUSSIRB:201626016). Informed consent was obtained from all subjects. All methods in the study were carried out in accordance with the Helsinki guidelines and declaration.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

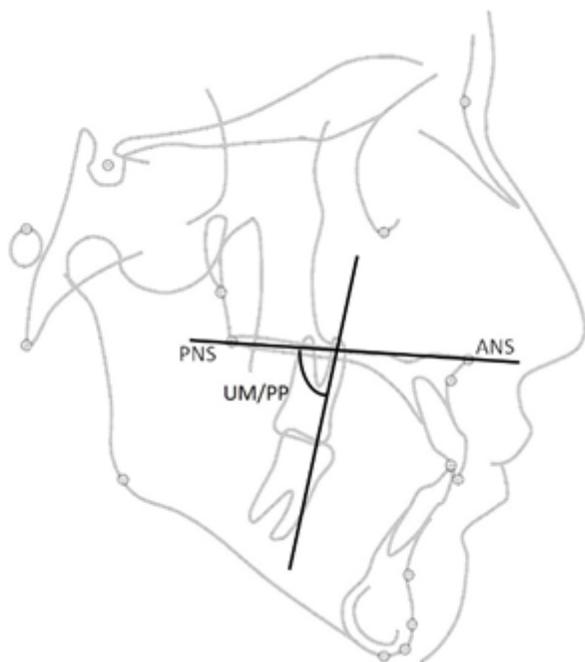


Figure 1

UM/PP is defined as the angle formed by the upper first molar axis and palatal plane

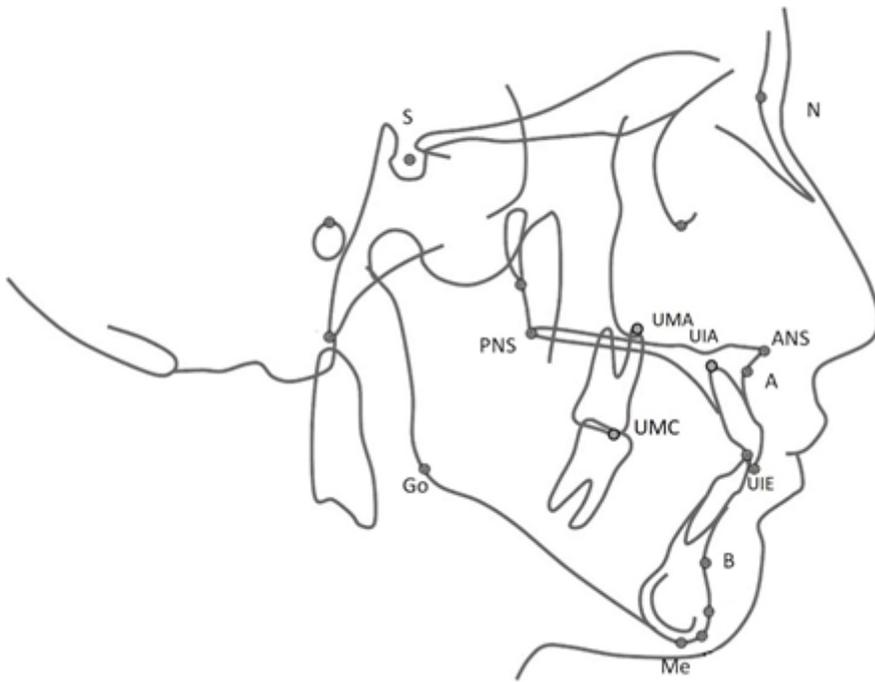


Figure 2

Landmark location. S: Sella; N: Nasion; A: A-point; B: B-point; ANS: Anterior Nasal Spine; PNS: Posterior Nasal Spine; UMA: Mesial buccal apex of the upper first molar; UMC: Mesial buccal cusp of the upper first molar; UIA: Apex of the upper middle incisor; UIE: Edge of the upper middle incisor; Me: Menton; Go: Gonion.