



Factors associated with spontaneous angular changes of impacted mandibular third molars as a result of second molar protraction

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Introduction: This study aimed to identify significant factors affecting the spontaneous angular changes of impacted mandibular third molars as a result of second molar protraction. Temporary skeletal anchorage devices in the missing mandibular first molar (ML-6) or missing deciduous mandibular second molar (ML-E) with missing succedaneous premolar spaces provided traction. **Methods:** Forty-one mandibular third molars of 34 patients (10 male and 24 female; mean age 18.3 ± 3.7 years) that erupted after second molar protraction were included in this study. They were classified into upright (U) and tilted (T) groups. Linear and angular measurements were performed at the time of treatment initiation (T1) and of ML-6 or ML-E space closure (T2). Regression analyses were used to identify significant factors related to third molar uprighting. **Results:** Nolla stage (odds ratio [OR] 4.1), sex (OR 0.003 for male), third molar angulation at T1 (OR 1.1), missing tooth space (OR 0.006), rate of third molar eruption (OR 23.3), and rate of second molar protraction (OR 0.2) significantly affected third molar uprighting. Age, third molar angulation at T1, rate of third molar eruption, and rate of second molar protraction were significant factors for predicting third molar angulation at T2. **Conclusions:** Available space for third molar eruption before and after second molar protraction is not associated with uprighting of erupting third molars. Older patients whose third molars are in greater Nolla stage, are in a more upright position at T1, and have a greater eruption rate have a greater chance for third molar uprighting. Alternatively, an increase in second molar protraction rate results in mesial tipping of the third molars. (Am J Orthod Dentofacial Orthop 2019;156:178-85)

Edentulous spaces caused by the extraction of mandibular first molars or congenitally missing premolars can be orthodontically treated by protraction of adjacent molars.¹⁻⁶ If the patients

have impacted third molars, protraction of the second molars to replace the missing mandibular first molars (ML-6) or retained deciduous mandibular second molars with missing succedaneous premolar spaces (ML-E) may lead to the eruption of impacted third molars.

Posterior available space is a significant factor for the eruption of impacted mandibular third molars,^{7,8} and high rates of third molar eruption have been reported after the extraction of the mandibular first molars.^{9,10} Although successful eruption of impacted third molars requires the establishment of proper mesiodistal angulation as the tooth erupts into the oral cavity,¹¹⁻¹³ the prognosis of erupted third molar angulations has been reported to be unpredictable. In some cases, the third molars are uprighted during the course of eruption, and in other cases they tip mesially, leading to difficulty in functioning and necessitating orthodontic uprighting.^{14,15} Third molar angulation changes are affected by various factors other than the available space, such as chronologic age and dental

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Table 1. Variables measured in this study

Variable	Definition
Linear measurements (mm)	
8MD	Mesiodistal width of the third molar
J-D7'	Available space for third molar eruption on the second molar crown level
J-DA7'	Available space for the third molar on the second molar distal root apex level
C8-OP	Vertical position of the third molar measured along the line perpendicular to the occlusal plane
Angular measurement (°)	
8-MP	Angle between the long axis of the third molar and the mandibular plane
Ratio	
J-D7'/8MD	Ratio of available space to the width of the third molar

age; moreover, the results of previous studies are conflicting.^{7,15,16}

Previous studies on the eruption of third molars have mostly focused on the natural dentition or on patients who had undergone extraction of premolars or second molars for orthodontic purposes.^{15,17-23} Few studies have investigated the spontaneous angular changes in the third molars when the second molars are protracted to close the spaces of the missing first molars or second premolars.

The purpose of this study was to identify significant factors that affected angulation changes in the impacted third molars as they erupt as a result of second molar protraction with the use of temporary skeletal anchorage devices (TSADs). The specific aims were to (1) assess the spontaneous angular changes of the impacted third molars after second molar protraction into the ML-6 or ML-E spaces and (2) identify significant factors that influence third molar uprighting.

MATERIAL AND METHODS

This retrospective clinical study was approved by the Institutional Review Board of Korea University Anam Hospital (ED17032), and all patients provided informed consent. All patients who had their mandibular third molars erupted by the protraction of second molars with the use of TSADs at a dental clinic from January 2003 to December 2016 were studied. The inclusion criteria for the study group were as follows: (1) space caused by missing ML-6 or retained ML-E (with a missing succedaneous mandibular second premolar) that had been successfully closed by the protraction of the second molars with the use of TSADs, (2) impaction of the mandibular third molar on the side of the missing space at the start of treatment, (3) third molars at Nolla stage 4 or greater, (4) second molar roots arranged parallel to the adjacent teeth at the time of missing space closure, and (5) third molars that had erupted without the application of any orthodontic forces. The exclusion criteria were as follows: (1) third molars partially or fully

erupted at the start of treatment, (2) malformed third molars that did not show normal eruption, and (3) chronic periodontitis with generalized alveolar bone resorption. For each patient, panoramic radiographs were acquired at the start of treatment (T1) and after the closure of the missing space (T2).

The third molars were classified into the upright (U) or tilted (T) group. The U group had upright third molars with roots parallel to the second molars at the end of second molar protraction (not at debonding). The T group had third molars erupted with mesial angulation and required orthodontic uprighting to obtain proper occlusion.

The mesiodistal width of the second molars of each patient was measured on casts with the use of a digital caliper (Mitutoyo, Japan). The ratio between the size of the second molars on the cast and that on the panoramic view was calculated to compensate for the error of magnification as previously described.¹⁷ The magnification rate was applied to all linear measurements. Definitions of the anatomic landmarks for the measurement of available posterior space and third molar angulations that were used in this study are defined in Table 1 and Figure 1. The study variables of linear and angular measurements are defined in Table 1. All the measurements were performed with the use of V-Ceph 6.0 software (Osstem, Seoul, Korea). The panoramic radiographs at T1 and T2 were digitized by a single investigator. The study variables were remeasured by the same investigator 3 weeks after the first measurement for analyzing intra-examiner reliability. The intraclass correlation coefficient was 0.90. Measurement error was estimated by means of the Dahlberg formula ($ME^2 = \sum d^2/2n$). Errors varied from 0.28 mm to 0.67 mm for linear measurements and from 0.12° to 0.54° for angular measurements.

Statistical analyses

The normality of all variables was tested by means of the Shapiro-Wilk test. All linear measurements, except the third molar angulations (8-MP) at T1 and T2, and

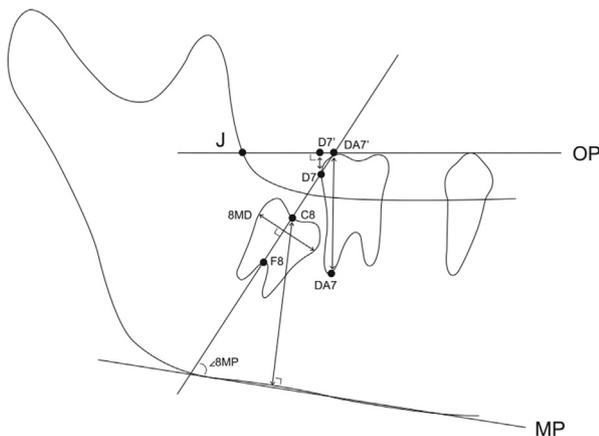


Fig 1. Landmarks used in this study. *OP*, occlusal plane constructed by connecting the cusp tip of the first premolar to the distal cusp tip of the second molar; *MP*, mandibular plane constructed by a line tangent to the lower border of the mandibular body; *J*, intersection between the anterior border of the ramus and *OP*; *C8*, center of the occlusal surface of the third molar; *F8*, furcation of the third molar; *D7*, the point of intersection between the *OP* and the line perpendicular to the *OP* and passing the most distal point of the second molar crown; *DA7*, the point of intersection between the *OP* and the line perpendicular to the *OP* and passing the most distal root apex of the second molar.

the changes from T1 to T2, showed normal distribution. Study variables measured at T1 and T2, and the changes from T1 to T2, were compared between the U and T groups by means of the independent *t* test for all variables except 8-MP. For 8-MP, the Mann-Whitney *U* test was used for intergroup comparisons.

To identify significant factors that lead to successful third molar uprighting, a binary logistic regression analysis was performed with the group variable (U or T) as an outcome variable. All of the studied variables and patient-related factors such as age, sex, protraction time, and Nolla stage at T1, were considered for inclusion in the regression model as covariates. In addition to the linear and angular measurements of the second and third molars, the rates of second molar protraction (at crown) and third molar eruption, calculated, respectively, by dividing the amounts of second molar protraction (difference in J-D7' from T1 to T2) and third molar eruption (difference in C8-OP from T1 to T2) by the protraction time, were included in the analysis as covariates. The odds ratios (OR) to have upright third molars at T2 was ascertained for each variable included in the final model.

A linear regression analysis was performed to predict third molar angulation at T2. All statistical analyses were

Table II. Descriptive statistics of the patients in this study

Variable	Male	Female	Total	P*
Number of patients (n)	10	24	34	
Number of third molars (n)	12	29	41	
Age at T1 (y)	18.5 ± 4.0	18.3 ± 3.6	18.3 ± 3.7	0.933
Nolla stage at T1 (n)	6.7 ± 2.3	6.5 ± 1.6	6.5 ± 1.8	0.807
Protraction time (y)	2.9 ± 0.7	3.0 ± 1.0	3.0 ± 0.9	0.562
Second molar protraction at the crown (mm)	5.8 ± 2.2	6.5 ± 2.6	6.3 ± 2.5	0.409
Second molar protraction at the root (mm)	6.4 ± 1.9	7.6 ± 2.3	7.3 ± 2.3	0.138

T1, start of treatment.

*Significance for the difference between male and female patients.

performed with the use of IBM SPSS Statistics for Windows (version 20.0; IBM Corp, Armonk, NY), and statistical significance was set at $P < 0.05$.

RESULTS

Forty-one mandibular third molars of 34 patients (10 male and 24 female; mean age 18.3 ± 3.7 years) were included in this study. Four patients whose third molars were malformed and did not show normal eruption were excluded. Descriptive statistics such as age, Nolla stage at T1, protraction time, and the amount of second molar protraction are presented in Table II. The mean protraction time of the second molars was 3.0 ± 0.9 years. Bodily protraction of the second molars to the position of the ML-6 or ML-E spaces was achieved; the amounts of second molar protraction at the crown and root apex were 6.3 ± 2.5 mm and 7.3 ± 2.3 mm, respectively (Table II).

As a result of second molar protraction, the angle of the impacted third molar showed maintenance (Fig 2), spontaneous uprighting (Fig 3), or spontaneous tipping (Fig 4). The mean third molar angulation change was $1.0 \pm 15.8^\circ$. It ranged from -23.7° (mesial tipping) to 51.3° (uprighting), indicating the various angular changes as the teeth erupted into the oral cavity (Table III). The mean third molar angulation (8-MP) for the U group at T2 was $82.0 \pm 10.2^\circ$, which was significantly greater than that of the T group ($54.2 \pm 17.2^\circ$; $P < 0.001$). Among the studied variables measured at T1, the U group had greater posterior available space at the second molar crown level and more upright third molars than did the T group, but the difference lacked statistical significance ($P = 0.106$ for J-D7'; $P = 0.081$ for 8-MP).

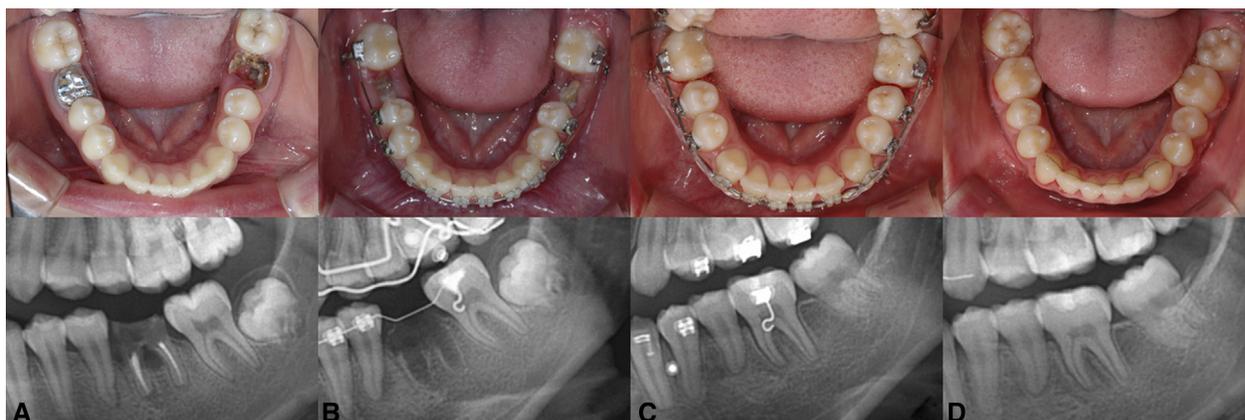


Fig 2. A case in which the third molar angulations are maintained. **A**, A 15-year-old female patient with a hopeless mandibular first molar and the third molar erupting in a slight mesial angulation (T1). **B**, After the extraction of the mandibular first molar, the second molar is leveled and protracted with the use of temporary skeletal anchorage devices (TSADs). **C**, As the mandibular second molar is protracted with the use of a TSAD, sufficient space is available for the eruption of the third molar, which then erupts spontaneously. The third molar erupts successfully without the application of any orthodontic force (T2). **D**, The treatment is completed with successful eruption of the third molar.



Fig 3. A case of spontaneous uprighting of the third molar. **A**, A 27-year-old male patient with a root canal-treated mandibular first molar and a completely horizontally impacted third molar (T1). **B**, The mandibular second molar is leveled after the extraction of the mandibular first molar. **C**, As the mandibular second molar is protracted with the use of a TSAD, the mandibular third molar is uprighted and erupts spontaneously into the oral cavity. **D**, After the extraction space is closed (T2), the tube is bonded to the third molar for orthodontic uprighting.

The binary logistic regression analysis showed that sex, Nolla stage, initial third molar angulation, missing tooth (ML-E or ML-6), second molar protraction rate, and third molar eruption rate significantly affected third molar uprighting (Table IV). Greater chance of third molar uprighting was expected in the third molars at a greater Nolla stage (OR 4.1; $P = 0.025$), greater angulation at T1 (OR 1.1; $P = 0.020$), and greater eruption rate of the third molars (OR 23.3; $P = 0.013$). The chance

decreased in male subjects (OR 0.003; $P = 0.031$), in cases of missing lower deciduous molars (OR 0.006; $P = 0.044$), and with an increase in second molar protraction rate (OR 0.2; $P = 0.020$).

According to the predictive model for third molar angulation at T2, ($P = 0.034$), third molar angulation at T1 ($P < 0.001$), second molar protraction rate ($P = 0.031$), and third molar eruption rate ($P < 0.001$) significantly affected the final third molar angulations

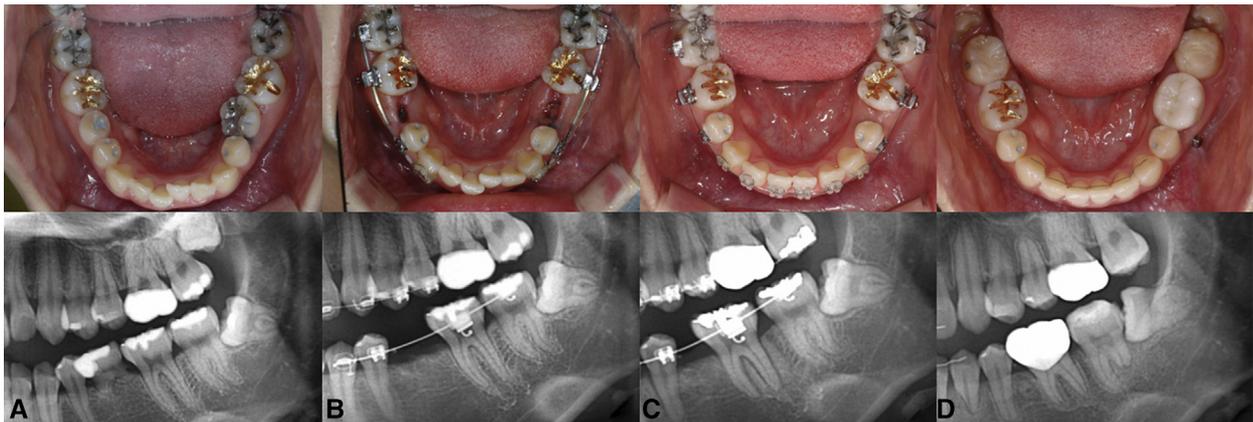


Fig 4. A case of spontaneous mesial tipping. **A**, A 19-year-old female patient with a missing left mandibular second premolar and a retained deciduous molar. The third molar is fully impacted. **B**, After the extraction of the second deciduous molar, leveling and alignment are done and space closure is in progress. **C**, As the second molar is protracted with the use of a TSAD, the third molar spontaneously tips mesially. **D**, After the closure of the extraction space, the third molar tips further mesially.

at the end of second molar protraction (Table V). An increase in patients' age, initial angulation, and third molar eruption rate increased the predicted third molar angulations at T2. In contrast, a greater protraction rate was associated with mesial tipping of the erupting third molars.

DISCUSSION

The missing spaces of ML-6 and ML-E are large owing to their crown sizes. The important point in space closure of long missing spaces is bodily movement, and TSADs allow large mesial molar movements with minimal loss of anchorage or the retraction of anterior teeth. In the present study, we confirmed the presence of parallel roots after space closure. The amounts of second molar protraction at the crown and root apex were 6.3 ± 2.5 mm and 7.3 ± 2.3 mm, respectively, showing an even greater amount of protraction of the root apex than of the crown (Table II).

Patients who had third molars in Nolla stages 1-3 were excluded because teeth in these stages have less than one-third of the crown formed, so accurate measurement of the angular changes is not feasible.

The missing molar space is not equal to the space gained from retained second deciduous molars. However, this study focused only on the spontaneous eruption pattern of the third molars as a result of second molar protraction. The amounts of second molar protraction at the crown and root apex were not statistically different in those who had missing molars or retained deciduous molars ($P = 0.895$ and $P = 0.256$ measured

at second molar crown and root apex, respectively); therefore, both groups of patients were included for analysis.

Among the variables that affect spontaneous third molar uprighting, the rate of third molar eruption was an important contributing factor, as evidenced by the greatest ORs and the regression coefficient with high statistical significance in the logistic regression analysis and the linear regression analysis, respectively. We performed a bivariate correlation analysis of the study variables at T1 and the rate of eruption to identify possible factors that affect the third molar eruption rate. The only significant factor was the vertical position of the third molar (C8-OP T1), which showed a significant positive correlation with the rate of third molar eruption; the more apically placed third molars tended to erupt faster ($r = 0.4$; $P = 0.010$). Despite the significant relationship between the vertical position of the third molars and the eruption rate, the C8-OP T1 was not statistically significant as an independent factor for predicting successful uprighting or estimation of the final third molar angulations.

The rate of second molar protraction had a negative effect on third molar angulations. As the second molar is mesialized, mesial movement of the third molar is expected to occur. However, when the space created for mesial movement was too large in a given period, the third molar crown tended to tip mesially. The ratio of eruption rate to protraction rate was calculated, and a significant difference was observed in the U and T groups. The U group had a mean ratio of 0.9 and the T group a mean ratio of 0.4, a statistically significant

Table III. Comparison of variables in the successful (U group, n = 21) and unsuccessful groups (T group, n = 20)

Variable	T1			T2			T1-T2			
	U	T	Total	U	T	Total	U	T	Total	
			P			P			P	
8MD (mm)	10.3 ± 1.2	10.3 ± 0.9	10.3 ± 1.0	0.981						
J-D7' (mm)	9.3 ± 2.4	8.2 ± 2.2	8.8 ± 2.4	0.106	15.5 ± 2.6	14.6 ± 3.3	15.1 ± 3.0	6.5 ± 2.2	6.3 ± 2.5	0.642
J-DA7' (mm)	9.3 ± 3.3	9.8 ± 2.6	9.5 ± 3.0	0.638	16.9 ± 2.6	16.7 ± 3.4	16.8 ± 3.0	6.9 ± 2.1	7.3 ± 2.3	0.365
C8-OP (mm)	6.3 ± 1.9	6.4 ± 2.4	6.4 ± 2.1	0.852	1.4 ± 1.6	3.7 ± 2.6	2.6 ± 2.4	-2.7 ± 1.9	-3.8 ± 2.5	0.004
8-MP (°)	74.2 ± 18.1	60.2 ± 23.8	67.4 ± 22.0	0.081	82 ± 10.2	54.2 ± 17.2	68.5 ± 19.8	-6.1 ± 15.4	1.0 ± 15.8	< 0.001
J-D7'/8MD	0.9 ± 0.3	0.8 ± 0.2	0.9 ± 0.3	0.125	1.5 ± 0.3	1.4 ± 0.3	1.5 ± 0.3	0.6 ± 0.3	0.6 ± 0.3	0.508

T1, start of treatment; T2, after second molar protraction.

Table IV. Odds ratios of the significant factors contributing to upright third molars after second molar protraction*

Factor	B	SE	df	P	Odds ratio	CI Lower	CI Upper
Sex	-5.8	2.7	1	0.031	0.003	0.0001	0.6
Nolla stage	1.4	0.6	1	0.025	4.1	1.2	14.2
8MP T1 (°)	0.1	0.04	1	0.020	1.1	1.0	1.2
Missing tooth	-5.1	2.6	1	0.044	0.006	0.0001	0.9
Protraction rate (mm/y) [†]	-1.7	0.7	1	0.020	0.2	0.04	0.8
Eruption rate (mm/y) [‡]	3.1	1.3	1	0.013	23.3	2.0	278.3
Constant	-12.8	5.8	1	0.026	0.0001		

*The accuracy of the final binary logistic regression model is 90.2%, with a Nagelkerke R² of 0.795; [†]Rate of second molar protraction calculated by difference in J-D7' from T1 to T2 divided by protraction time; [‡]Rate of third molar eruption calculated by difference in C8-OP from T1 to T2 divided by protraction time.

Table V. Predictive model of the final third molar angulations at the end of second molar protraction (8-MP T2)*

Factor	B	SE	β	t	P
Age (y)	1.4	0.6	0.3	2.2	0.034
8-MP T1 (°)	0.7	0.1	0.8	7.1	< 0.001
Protraction rate (mm/y) [†]	-3.7	1.6	-0.2	-2.2	0.031
Eruption rate (mm/y) [‡]	9.1	2.3	0.4	3.9	< 0.001
Constant	-9.7	16.9		-0.6	0.571

*The adjusted R² is 0.643; [†]Rate of second molar protraction calculated by difference in J-D7' from T1 to T2 divided by protraction time; [‡]Rate of third molar eruption calculated by difference in C8-OP from T1 to T2 divided by protraction time.

difference (P = 0.023). This indicates that a balance between the eruption speed and protraction speed is critical for successful third molar eruption.

Greater mesial tipping of the third molars was observed in patients with ML-E than in patients with ML-6. To identify the reason for this difference, we compared the study variables for the groups with missing ML-6 or ML-E space. Although the amount of second molar protraction (P = 0.585) and protraction time (P = 0.913) were not statistically different, the group with ML-E space had significantly less space distal to the second molar crown at T1 (J-D7' for ML-E 7.7 mm, for ML-6 9.5 mm; P = 0.016) and at T2 (J-D7' for ML-E 13.8 mm, for ML-6 16.0 mm; P = 0.016). In addition, the patients who had ML-6 space showed a significantly greater rate of third molar

eruption than did those who had ML-E space ($P = 0.049$).

Initial third molar angulation was a significant factor in predicting successful third molar uprighting. The correlation between the third molar angulations at T1 and T2 was highly significant ($P < 0.001$) with a Pearson correlation coefficient of 0.718. Female patients showed a significantly greater chance for spontaneous uprighting. We think this is because female patients had more upright third molars than did male patients at T1 (8-MP T1 for male 56.5° , for female 71.9° ; $P = 0.039$), rather than because of any sex difference.

A tendency for greater uprighting was observed in older patients and in third molars that were in the later stages of development. Third molars with an increase of 1 Nolla stage at T1 had an approximately 4-fold greater chance of having upright third molars at T2; moreover, an increase in age by 1 year resulted in an increase of 0.3° of predicted third molar angulation at T2. This indicates that more developed teeth in older patients tend to spontaneously upright more often with an increase of available space, while teeth in their early developmental stages in younger patients tend to mesially tip into the available space created. According to a previous study on third molar eruption after second molar extraction,¹⁵ the effect of Nolla stage was contrary to our results, showing that an increase in Nolla stage leads to the mesial tipping of third molars. This difference may be attributed to the different clinical situations in which de-la-Rosa-Gay et al extracted the second molars and the lack of any protraction force applied to the adjacent tooth. Possible effects of periodontal tissues, such as gingival fibers and periodontal ligaments, between the second and third molars may have brought about different results, but further study is warranted to confirm this speculation.

The amount of available space created for third molar eruption was not a significant factor for third molar uprighting. All patients had the missing spaces closed by means of molar protraction with the use of TSADs, but 20 of the 41 erupted third molars showed mesial tipping and required orthodontic uprighting. In fact, the group with tilted third molars even had a greater mean amount of second molar protraction.

The main limitation of our study is that it was a retrospective study, and the number of teeth studied in each Nolla stage was relatively small. Further studies with a larger sample size may lead to a better understanding of the effects of dental developmental stages on the eruptive changes of third molars. Although previous

studies have shown that vertical linear measurements and angular measurements on panoramic radiographs are reliable in the posterior region,^{24,25} 3-dimensional studies of third molar eruption with the use of cone-beam computed tomography may provide more accurate results. However, this was a retrospective study, and only panoramic radiographs taken at the beginning of treatment, after second molar protraction, and after orthodontic treatment were available. Furthermore, the mean protraction time was 3.0 ± 0.9 years and the protraction rate and eruption rate were calculated by dividing the amount of tooth movement by total protraction time. Additional prospective studies with more accurate assessment of protraction rate with the use of plaster models or digital scans may be warranted. Because the second molar protraction rate can be controlled by the clinician, the eruption rate of the third molars could not be fully explained by our study variables, and this aspect also warrants further studies.

CONCLUSIONS

On the basis of this study on the spontaneous angular changes of impacted mandibular third molars as a result of the protraction of second molars with the use of TSADs into the missing ML-6 or ML-E space, we conclude the following:

1. Older patients with more developed third molars tend to have spontaneous uprighting of third molars.
2. Available space for third molar eruption before and after second molar protraction is not associated with uprighting of erupting third molars.
3. More upright third molars before second molar protraction have a greater chance of spontaneous uprighting during eruption.
4. Greater eruption rate of third molars is associated with third molar uprighting.
5. Increased rate of second molar protraction may result in mesial tipping of the third molars.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at <https://doi.org/10.1016/j.ajodo.2018.08.024>.

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