Original Article

Interference factors regarding the path of insertion of rotational-path removable partial dentures

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ABSTRACT

Background: The aims of this study were to evaluate the effect of the location of the rotational center and the morphology of teeth resulting in interference with the rotational path of insertion and to estimate when an interference test should be performed.

Methods: A total of 400 dental radiograms of maxillary and mandibular first and second molars (100 for each position) were selected. The radiograms were used to hand-sketch the outlines on tracing paper. Then, an interference test was simulated using calipers. Mesial long occlusal rest seats with three different lengths were designed. A curve-simulated rotational path was drawn on the tracing paper showing the outline of a molar. If the curve was intersected by the mesial outline, interference was occurred. A total of 1200 tests were performed.

Results: A significant number of interference cases (18.5%, N = 400) occurred when the rotational center was placed at the most distal margin of the occlusal surface. The interference was reduced (2.75%, N = 400) but still present at the distal fourth of the occlusal surface. At the distal one-third of the occlusal surface, interference did not occur (0%, N = 400). There was a significant difference between the results of the three rotational centers (p < 0.0001).

Conclusions: The interference test was not required for a rotational center at the distal third to half of the occlusal surface. However, if the length of the long occlusal rest extends beyond the distal third, an interference test is recommended before final impression.

Rotational paths of insertion have been used for removable partial prosthodontics for many decades [1]. In the literature, the majority of studies have described the clinical application of the rotational path of insertion in cases with anterior missing teeth [2–15], tilted mandibular molars [2,3,6–8,10,13–16] and unilateral single missing spans with tilted abutment teeth [17]. Few of the studies discuss the rationale and principles of the rotational path [6–9,12–14,16].

Unfortunately, clinical [15,18] and laboratory studies [19–21] are scarce.

When a rotational path is applied to tilted mandibular molars, it has been suggested preparing two mesial long occlusal rest seats on the occlusal surface of the two distal abutments (two tilted mandibular molars). The length of the long rest should be larger than half of the mesio-distal dimension of the tooth [6–8,13–16], and the terminal end of

At a glance commentary

Scientific background on the subject

When a rotational path removable partial denture is applied to tilted mandibular molars, two mesial long occlusal rest seats are suggested. The length of the long rest should be larger than half of the mesio-distal dimension of the tooth. However, the longer length will also at the same time induce interferences easier at the mesial side during denture insertion.

What this study adds to the field

The aims of this study were to evaluate the effect of the location of the rotational center and the morphology of teeth resulting in interference with the rotational path of insertion and to estimate when an interference test should be performed.

the rest seat should correspond to the rotational center of the denture. Therefore, an imaginary line connecting the two rotational centers is considered a rotational axis along which the removable partial denture is rotated into position. The advantages of the rotational path design are the ability to engage mesial undercut that is difficult with the conventional method and the ability to eliminate the buccal and lingual clasps, reducing coverage of the tooth and the risk of caries [6,7,13,14,16]. This rest seat design with asymmetrical, long, deep, parallel walls is mainly used to compensate for encirclement and bracing that was originally provided by the clasps of a conventional retentive assembly [6−8,13−16]. Some authors further suggest that a longer rest reduces the blocking out over the distal surface of the anterior abutment [15]. However, this effect does not mean that the length of the rest can be extended without limits. The longer length will provide better support, retention, and stability; nevertheless, it will also at the same time induce interferences easier at the mesial side during denture insertion.

In the case of mandibular tilted molars, mesial undercuts of distal abutments were usually large. Some authors worried that large undercuts will interfere with the rotational path during denture insertion. Therefore, in the diagnostic phase, the authors suggested that an interference test should be conducted first to find out the possible interference which occurred at the mesial side of the distal abutment during inserting the rotational path denture [8,13,17]. In the interference test, one tip of the caliper is placed at the end of the long rest, i.e., the center of rotation. The second tip is placed in the proximal undercut area and rotated occlusally. If the second caliper tip can be rotated occlusally without being trapped proximally, the undercut and the center of rotation are properly aligned. If the caliper tip is trapped and unable to rotate freely, it means that an interference is occurred. In this situation, mesial surface of the distal abutments should be recontoured before the master cast impression [8,13,14,22] or the location of rotation center should be adjusted.

To obtain precise results from the interference test, a block-out instrument [22] rather than simple calipers should be used because the rotational path removable partial denture (RPD) is rotated along a rotational axis rather than a rotational center. However, the block-out instrument method is more time-consuming and more complicated than the caliper method [22]. Therefore, a study to investigate the factors determining the interference of the rotational path on the mesial surface of the tilted molars in the rotational path RPD is necessary.

Besides, teeth vary in their morphologies, but there are still some universal principles that may cause some teeth easier to induce interferences during rotational path than other teeth. These are the factors needed to figure out in order to understand the interference is related to the length of the long occlusal rest, or the natural morphology of the mesial surface of the molars, or both.

The results of this study can provide clinical guidelines for determining the location of the rotational center and deciding whether an interference test should be performed or not.

Materials and methods

This study was approved by the Institutional Review Board of Keelung Chang Gung Memorial Hospital (100-2366B). The aim of this study was to investigate the effects of different rotational center positions on interference with the rotational path and the natural morphology of molars. Radiographic films of maxillary and mandibular first and second molars were randomly selected from the radiographic records of the Department of Dentistry, Keelung Chang Gung Memorial Hospital. The inclusion criteria were as follows:

1. A parallel radiography technique was preferred. Radiographic films with overlapping buccal and lingual (palatal) cusps were judged based on a parallel technique.
2. Bitewing film was always taken with the parallel technique.
3. Overlapping between anterior and posterior teeth was not allowed. Mesial and distal surfaces (profiles) were required to be well defined. The mesial surface of posterior teeth was not allowed to be covered by the proximal surface of the neighbor anterior teeth to allow detection of the mesial surface profile.
4. The cemento-enamel junction (CEJ) was required to be clear.
5. The molars selected had no caries and no previous restoration.
6. If a patient had more than one radiographic film for the same position, the earliest one was selected.

All screening was performed by the same experienced prosthodontic doctor. Maxillary, mandibular, first and second molars (100 each) were selected, resulting in a total of 400 teeth. A digital single-lens reflex camera (Canon EOS Digital N, Canon Inc., Japan) was used to capture the digital images of the radiographic films. The camera was mounted on a camera copy stand with constant settings (aperture F/9; focal distance 34 mm; exposure time 1/125 s; ISO 200). The selected
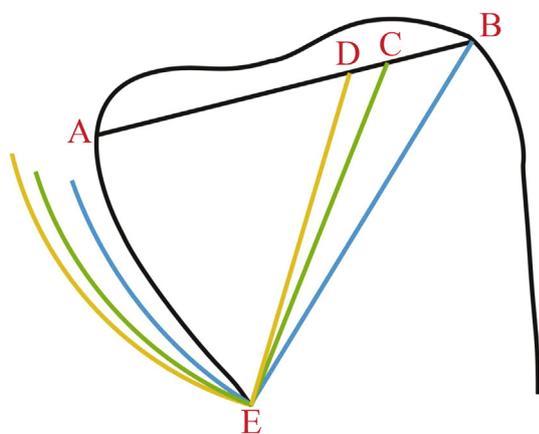
Fig. 1 Schematic diagram of a left tilted molar. A, mesial end of occlusal table; B, at the most distal end of occlusal table (Position 1); C, at the most distal fourth of the mesio-distal dimension of the occlusal surface (Position 2); D, at the most distal one-third of the mesio-distal dimension of the occlusal surface (Position 3); E, cement-enamel junction.

radiographic films were secured on a fixed area over a LED viewing box that was placed on the base of the copy stand.

After the radiographic films had been converted to digital images by the digital camera, the images were then printed on a laser printer (HP LaserJet 1010, Hewlett-Packard Company, CA, USA.) on A4 size paper. The outlines of the selected teeth were then hand-sketched on semi-transparent tracing paper. Thus, a total of 400 outlines of the selected teeth were obtained.

Calipers were used to simulate the rotational path of insertion to test the interference with the mesial surface of the tested molars. In the literature, the length of the long occlusal rest seat was suggested to be longer than half of the mesio-distal dimension of the occlusal surface of the molar [6−8,13−16]. The mesio-distal dimension of the occlusal table in this study was defined as the distance between the boundary of the mesial and distal marginal ridges [Fig. 1A & B]. In this study, three different lengths of long occlusal rests (representing different locations of the rotational center) were designed. All of these distances were longer than half of the mesio-distal dimension of the occlusal surface.

1. Position 1: at the most distal end (distal marginal ridge) [Fig. 1B];
2. Position 2: at the most distal fourth of the mesio-distal dimension of the occlusal surface [Fig. 1C];
3. Position 3: at the most distal one-third of the mesio-distal dimension of the occlusal surface [Fig. 1D].

A simulated interference test was performed on the tracing paper. The three positions of the designed rotational center and the cement-enamel junction were marked on the outlines. The radius of the rotational path of insertion was the distance between the designed rotational center [Fig. 1B, C & D] and the cemento-enamel junction [Fig. 1E] over the cervical area of the mesial surface of the tooth [8,13,14,22]. This diagonal line was

the longest distance between the rotational centers and the tooth surfaces. If interference did not occur in the rotational movement within this radius, it could not occur with a shorter rotational radius. A curved line was drawn on the tracing paper with a designed rotational center and corresponding rotational radius by using calipers. Intersection of the curved line with the mesial surface of the molar indicated that interference had occurred. Four-hundred molars were tested, and three tests were performed for each tooth, resulting in 1200 tests.

The gender and age at the time that the radiograph was taken were recorded. The interference number was also recorded for each tooth position. The calculation of the percentage of interference was performed as follows:

The percentage of interference for a tooth type with a certain rotational center position = number of interference occurrences for the tooth type with that rotational center position/(total number of samples of the tooth type with that rotation center position) × 100%.

All data were statistically analyzed using the SPSS version 17 (SPSS, Chicago, IL, USA) computer statistical software. The Pearson Chi-Square test was performed to compare the differences between groups, and Fisher's exact test or Likelihood Ratio value was used when cell count was below five for each cell. Generalized estimating equation test was used to compare the data between different rotational centers in the same tooth type. A p value <0.05 was considered statistically significant.

Results

In the study, the male to female ratio was 1:0.688 (77: 53). The ages at the time that the radiographs were taken were 9.0−59.9 years, and the average age was 27.84 (SD ± 10.88) years [Fig. 2].

The percentages of interference of the maxillary first molars were 27% at Position 1 and 5% at Position 2. For the maxillary second molars, the percentages were 12% at Position 1 and 1% at Position 2. For the mandibular first molars, the percentages were 28% at Position 1 and 5% at Position 2. For the mandibular second molars, the percentages were 7% at Position 1 and 0% at Position 2. At Position 3, there was no interference in any of the tooth positions [Table 1].

The comparison between rotational centers in the same tooth type was limited to compare position 1 and position 2 only because there was no interference occurred at position 3. The percentages of interference at different rotational centers in the same tooth type were significantly different in maxillary first molars ($p < 0.0001$), maxillary second molars ($p = 0.007 < 0.05$), mandibular first molars ($p < 0.0001$), and in all molars ($p < 0.0001$) [Table 2]. No statistics were computed for mandibular second molars because there was no interference occurred in position 2 of these teeth.

The interference percentages of different tooth types for the same rotational center were significantly different among the four tooth types at position 1 (at the most distal end) ($p < 0.0001$). When the rotational center was moved to position 2 (at the most distal fourth of the mesio-distal dimension of the occlusal surface), a significant difference was still present among the four tooth types ($p = 0.017 < 0.05$). When the rotational center was moved to Position 3 (at the most distal
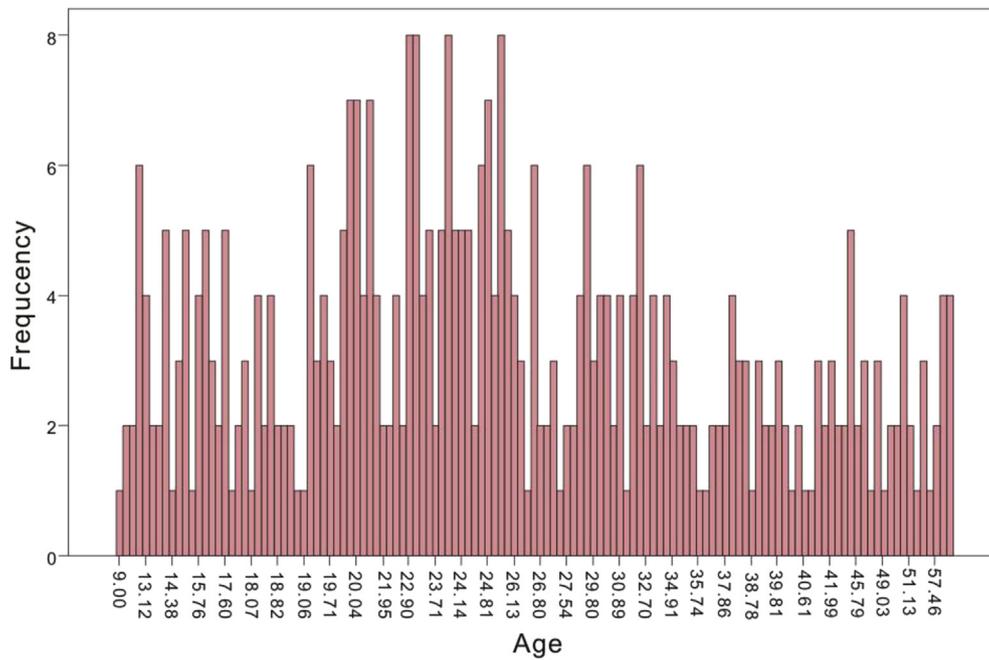
Fig. 2 Age distribution of patients when the radiographic films were taken. Sample distribution was deviated to the left (younger group).

one-third of mesio-distal dimension of occlusal surface), statistics were not performed because no interference occurred in any of the tooth samples [Table 3].

To analyze the relationship among different types of tooth, the four tooth types were divided into the following two groups: the first molar group, including maxillary first molars and mandibular first molars, and the second molar group, including maxillary second molars and mandibular second molars. There was a significant difference between the first molar group and the second molar group at rotational center position 1 (at the most distal end) ($p < 0.0001$). When the rotational center was moved to position 2 (at the most distal fourth of the mesio-distal dimension of occlusal surface), a significant difference was still present between the two groups ($p = 0.011 < 0.05$). When the rotational center was moved to position 3 (at the most distal third of the mesio-distal dimension of the occlusal surface), statistical analyses

were not performed because no interference occurred in any of the tooth samples [Table 4].

With different grouping consideration, all samples were re-divided into the following two groups: the maxillary molar group and the mandibular molar group. There was no significant difference between the maxillary molar group and the mandibular molar group at rotational center Position 1 ($p = 0.607 > 0.05$) and Position 2 ($p = 1.000 > 0.05$). No statistics were performed at Position 3 because no interference occurred in any of the tooth samples [Table 5].

There was no gender effect on the interference test ($p > 0.05$) [Table 6].

Table 1 The percentages of interference for different tooth types and different rotational center positions.

Tooth type	Rotational center position		
	1. Most distal	2. Distal 1/4	3. Distal 1/3
Maxillary first molar (N = 100)	27%	5%	0
Maxillary second molar (N = 100)	12%	1%	0
Mandibular first molar (N = 100)	28%	5%	0
Mandibular second molar (N = 100)	7%	0	0
Total (N = 400)	18.5%	2.75%	0

Table 2 Comparison between different rotational centers (position 1 and 2[a]) in the same tooth type.

Tooth type	GEE[b]	df	p value
	Wald Chi-Square value		
1. Maxillary first molar (N = 300)	20.742	1	<.0001[c]
2. Maxillary second molar (N = 300)	7.234	1	.0070[c]
3. Mandibular first molar (N = 300)	21.628	1	<.0001[c]
4. Mandibular second molar (N = 300)	[d]		
Total (N = 1200)	52.732	1	<.0001[c]

a No statistics were computed because 'Position 3' was constant.
b GEE: Generalized estimating equation.
c A p value of <0.05 was considered statistically significant.
d No statistics were computed because 'Position 2' in 'Mandibular second molar' was constant.

Table 3 Comparison between different tooth types with the same rotational center.

Rotation center position	Chi-Square value	df	p value
Position 1: most distal (N = 400)	22.351	3	<.0001[a,b]
Position 2: distal 1/4 (N = 400)	10.147	3	.017[b,c]
Position 3: distal 1/3 (N = 400)	[d]		

[a] Pearson Chi-Square value.
[b] A p value of <0.05 was considered statistically significant.
[c] Likelihood Ratio value was used when cells count was below five for each cells.
[d] No statistics were computed because Position 3 was constant.

Table 4 Comparison between different tooth groups (first molar group and second molar group) at the same rotational center.

Rotational center position	Chi-Square value	df	p value
Position 1: most distal (N = 400)	21.489	1	<.0001[a,b]
Position 2: distal 1/4 (N = 400)	—	1	.011[b,c]
Position 3: distal 1/3 (N = 400)	[d]		

[a] Pearson Chi-Square value.
[b] A p value of <0.05 was considered statistically significant.
[c] Fisher's exact test was used when cells count was below five for each cells.
[d] No statistics are computed because Position 3 was constant.

Discussion

The percentages of interference were compared at three different rotational center positions and it was found that there were significant differences between different rotational center positions in the same tooth type ($p < 0.0001$) [Table 2]. Applying mathematical rules, a larger radius of the curvature corresponded to a flatter curvature of the surface; conversely, a shorter radius of curvature corresponded to a steeper curvature of the surface. Interference was reduced when the rotational center was moved from Position 1 to Position 2 and in turn to Position 3 because the radius of rotation became

Table 5 Comparison between different tooth groups (maxillary molar group and mandibular molar group) at the same rotational center.

Rotation center	Chi-Square value	df	p value[a]
Position 1: most distal (N = 400)	.265	1	.607[b]
Position 2: distal 1/4 (N = 400)	—	1	1.000[c]
Position 3: distal 1/3 (N = 400)	[d]		

[a] A p value of <0.05 was considered statistically significant.
[b] Pearson Chi-Square value.
[c] Fisher's exact test was used when cells count was below five for each cells.
[d] No statistics are computed because Position 3 was constant.

Table 6 Gender differences in the same tooth type and the same rotational center.

Tooth type	Rotation center	Chi-Square value	df	p value[a]
1 Maxillary first molar (N = 100)	Position 1	.003	1	.957[b]
	Position 2	—	1	.652[c]
	Position 3[d]	—	—	—
2 maxillary second molar (N = 100)	Position 1	.457	1	.499[b]
	Position 2	—	1	.410[c]
	Position 3[d]	—	—	—
3 mandibular first molar (N = 100)	Position 1	.949	1	.330[b]
	Position 2	—	1	.654[c]
	Position 3[d]	—	—	—
4 mandibular second molar (N = 100)	Position 1	—	1	.417[c]
	Position 2[d]	—	—	—
	Position 3[d]	—	—	—

[a] A p value of <0.05 was considered statistically significant.
[b] Pearson Chi-Square value.
[c] Fisher's exact test was used when cells count was below five for each cells.
[d] No statistics are computed because the positions were constant.

shorter, and the curvature became steeper. Within the limitations of our data, no interference was detected at Position 3.

When the tooth morphology was studied, the curvature and profile of the axial surfaces of the teeth provided their physiologic functions. A tooth with the correct contour can protect the gingiva and provide proper gingival stimulation from food flow during mastication [23]. Although there are some variations in the normal tooth morphology, these variations and differences may be within physiologic limits [23,24]. In the normal-type trait, the first molar is larger than the second molar [24]. Therefore, the first molar has a larger occlusal table than the second molar. At rotational center position 1 or 2, the first molar group had more interferences than the second molar group, and this difference was significant because of the longer radius of rotation [Table 4].

Only the first and second molars were included in this study. Other tooth types, such as third molars and premolars, were excluded in this study. Third molars exhibit a wide range of variation [24], and it is difficult to capture their images without distortions. Therefore, it is difficult to obtain stable results. Premolars are teeth often used as abutments for the rigid retainers of category I anterior—posterior type rotational path designs [7,8,13–16,18]. However, because the premolars have smaller size than molars and there are not too much variations in their axial morphology, interference should not occur in premolars according to the same rules described previously. Therefore, premolars were excluded from this study.

There was no significant difference between genders [$p > 0.05$, Table 6]. The age distribution of the samples deviated to the left (younger group) [Fig. 2] because the radiographic films of younger patients were intended to be selected to avoid the destruction of natural tooth morphology by diseases or natural attrition.

The mesial surfaces of tilted molars interfering with the rotational path may be a misconception. The undercut related to the perpendicular line to the occlusal plane becomes larger when the molar is mesially tilted (in the conventional path of
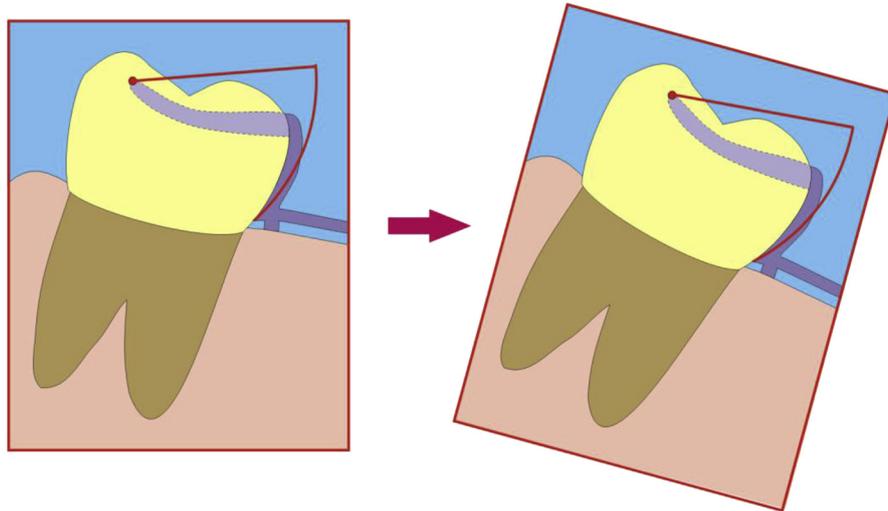
Fig. 3 Schematic diagram of a tilted molar. The relationship between the rotational center and rotational path does not change when the tooth tilts.

insertion). However, for the rotational path, interference is not related to the degree of tilting of the molar because the relationship between the rotational center and the mesial surface does not change when the molar is tilted or not [Fig. 3].

Within the limitations of this study, it was concluded that a small percentage of interference occurred when the rotational center was positioned at the distal end of the occlusal surface. When the rotational center was moved mesially to the distal fourth of the occlusal surface, interference was reduced but was still present. Furthermore, when the rotational center was moved mesially to the distal one-third of the occlusal surface, interference did not occur. Therefore, when designing a category I posterior−anterior rotational path denture with the rotational center at the distal third to half of the occlusal surface, the interference test is not needed. However, in some situations with occlusal problems, the rotational center is designed at the distal end of the occlusal surface [Fig. 4]. As a result, interference (0−28%) may occur and an interference test is recommended before making a master model.

Using study cast seems to be feasible in such a study, but only standalone teeth without anterior or posterior adjacent teeth can provide a clear proximal surface. Besides, some teeth are still partially erupted and covered by soft tissue which make their CEJ, the designated reference point of our study, difficult to be identified. On the other hand, using radiograms is an easier method to implement. The magnifying rate for radiograms is not a problem because this study measures only the surface curvatures of the teeth, not the dimensions. Considering a study base on two-dimensional scale, it is acceptable to select a suitable plane from a tooth to observe the result. The study objects are the teeth in the selected radiograms which their mesial or distal sides are clear-identified, not covered by adjacent teeth and their CEJs can be located. Consequently, the results will not be affected by other reasons such as distortion.

There is no related research about this topic in the past. As a precedent study, a two-dimensional model that is easier to

control the variables of the study is chosen. However, tooth is a three-dimensional structure. Therefore, in the future, a study of three-dimensional models should be designed to acquire more information and provide more guidance for clinicians.

Conclusion

Within the limitations of this study, it is concluded that, for a category I posterior−anterior rotational path denture, the rotational center should be designed at the distal third to half of the occlusal surface of the molar. In such a design,

Fig. 4 The rest of a unilateral rotational path removable partial denture was designed at the distal and lingual side because there was tight occlusion at the mesial marginal ridge.

interference does not occur, independent of the degree of tilting of the molars. Therefore, the interference test is not needed if the rotational center is well designed.

Conflicts of interest

The authors declare that they have no competing interests.

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