치의과학박사 학위논문

Reproducibility of eccentric tooth contact on a semi-adjustable articulator using T-scan

반조절성 교합기에서 T-scan 을 이용한 편심위 교합 접촉의 재현성

2020 년 8 월

서울대학교 대학원

치의과학과 치과보철학 전공

정 민 영

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- ABSTRACT -

Reproducibility of eccentric tooth contact on a semi-adjustable articulator using T-scan

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Purpose: Semi-adjustable articulators have been used to simulate mandibular movements and occlusal relationships. However, it has reported that semi-adjustable articulator could not duplicate accurately human mandibular movement. Several previous studies have analyzed articulator movement, however, few have compared excursive tooth contact on articulator with the tooth contact during actual mandibular movement. The purpose of this study was to evaluate the concordance of semi-adjustable articulator contacts with intraoral contacts during eccentric movements using the T-scan.

Materials and methods: Irreversible hydrocolloid impressions of upper and lower arches were taken from twenty-seven subjects to create dental stone casts. Before mounting, the maxillary casts of all subjects were scanned using a model scanner. Maxillary casts were mounted in a semi-adjustable articulator (PROTAR Evo 7) using the KaVo ARCUS facebow. Mandibular casts were mounted in maximum intercuspal

position without any registration. The condylar guidance angle was set according to protrusive and lateral intraoral records taken using polyvinyl siloxane. Three recordings of right and left excursive mandibular movement and protrusive mandibular movement were taken using the T-scan v9.1 on supine position. The same procedure was performed for the articulator. The stereolithography (STL) files for the maxillary cast were aligned to the arch in the T-scan software. The interocclusal record from maximum intercuspation was used as a reference for positioning. The complete mandibular movement was divided into four time points for analysis, from T0 to T3. T0 represented the beginning of a jaw movement in one direction and T3 represented the point when all teeth on the non-working side for the right and left excursion and all posterior teeth for protrusion were completely separated. The time point halfway between T0 and T3 was defined as T1 and that three-quarters of the way between T0 and T3 as T2. The concordance of intraoral and articulator occlusal contacts were calculated at T0, T1, T2, and T3. The concordance of all teeth, and of the working and balancing sides (anterior and posterior teeth for protrusion), were calculated respectively. Intraclass correlation coefficient (ICC) analysis was used to evaluate the reproducibility of repeated tests. Repeated measures analysis of variance (RM-ANOVA) was used to analyze differences between concordances of intraoral and articulator contacts according to the direction of mandibular movement, time, and working and balancing sides. Bonferroni post hoc tests were used to examine the significant differences. All statistical analyses were conducted at the confidence level of 99%.

Results: For all teeth, concordance between intraoral and articulator occlusal contacts during excursive mandibular movement was greatest at T0, with decreasing tendencies at T1 and T2, and was increased at T3. Concordances of all teeth between intraoral and articulator occlusal contacts at T3 were 85.2±10.4% on the right excursion, 85.0±9.4% on the left excursion, and 85.7±11.1% on the protrusive excursion. There were no significant differences among the concordances of right lateral, left lateral, and protrusive excursion. There were significant differences among the concordance between intraoral and articulator occlusal contacts during all excursive movements over time. When comparing concordances of the working sides during lateral excursion, concordance between intraoral occlusion and articular contacts of the working side at T0 was significantly lower than at T3. The rates of positive occlusal error on the working side at T3 were 18.10% on right excursion and 15.49% on left excursion, and the rate of the anterior side was 14.62% on protrusive excursion. The rates of positive occlusal error on the balancing side at T3 were 1.72% on right excursion and 2.12% on left excursion, and that of the posterior side was 2.63% on protrusive excursion. All ICC values of eccentric movements evaluated using the T-scan showed better than moderate reliability. Most ICC values for the mandible were higher than those for the articulator.

Conclusions: As a result of assessment of the concordance between semi-adjustable articulator contact and intraoral contact during eccentric movement using T-scan, the concordance changed during excursive mandibular movements. When comparing intraoral and articulator contacts during lateral eccentric mandibular movement, concordance on the working side was significantly lower at T3 than at T0. Occlusal adjustment of the working side might be required after prosthesis delivery. When the balancing side (for lateral excursion) or posterior teeth (for protrusive excursion) were discluded, there were positive occlusal errors. Although these values are low, it is essential to consider the possibility that occlusal adjustment will be necessary on the balancing side after prosthesis delivery.

Keywords : semi-adjustable articulator, T-scan, eccentric tooth contact, checkbite, occlusal contact

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CONTENTS

I. INTRODUCTION

Articulators are used for precise diagnosis and restoration in restorative dentistry. (Mohamed SE et al., 1976) Clinicians use semi-adjustable articulators to simulate the patient's mandibular movements and occlusal relationships (Donegan SJ et al., 1991, Celenza FV, 1979), which aids in the fabrication of restorations and prostheses by enabling occlusal adjustments on the articulator and thereby requiring less intraoral occlusal adjustment. (Weinberg LA, 1963, Bailey JO et al., 1984, Dos Santos et al., 2003) However, it has reported that a semi-adjustable articulator could not duplicate accurately human mandibular movement. (Shanahan et al., 1959, Clayton JA, 1971, Hobo et al., 1976, HC Wachtel et al., 1987, Chou TM et al., 1987, Dos Santos et al., 1988) Shanahan et al. reported that natural protrusive movements are not simulated well by articulators due to the straight line movement. (Shanahan et al., 1959) Clayton found that 50% of restorations made on semi-adjustable articulators required intraoral occlusal adjustment. (Clayton, 1971) Hobo et al. reported that no existing articulator can duplicate every possible mandibular movement. (Hobo et al., 1976) Wachtel et al. noted that semi-adjustable articulators are limited by their inability to duplicate the posterior determinants of occlusion. (Wachtel et al., 1987) Dos Santos et al. evaluated six different types of semi-adjustable articulators and detected significant differences between real mandibular movements and those of semi-adjustable articulators. (Dos Santos JJ et al., 1988) Chou et al. analyzed the reproducibility of mandibular movement by articulators using an LED mandibular tracing device and found that it was significantly low in the horizontal plane. (Chou TM et al., 1987)

If a semi-adjustable articulator does not accurately reproduce human mandibular movement, prostheses made using the articulator are more likely to have occlusal errors. Hobo et al. classified articulator-related occlusal errors as positive or negative. Positive errors occur when the articulator undercompensates for mandibular movement, and negative errors occur when the articulator overcompensates the mandibular movement. (Hobo et al., 1976) Few studies have evaluated the ability of articulators to reproduce excursive tooth contacts during mandibular movement. Tamaki et al. analyzed the reproduction of excursive tooth contacts by an articulator set up using computerized axiography and found that the articulator reproduced 82% of the protrusive tooth contacts and 90% of the laterotrusive tooth contacts. (K. Tamaki et al., 1997) Caro et al. assessed lateral excursive tooth contacts produced using a semi-adjustable articulator with articulating paper and found that it reproduced the intraoral contacts 82% with canine guidance, 40% with anterior guidance, and 0% with group function. (AJ Caro et al., 2005)

Previous studies used wax and articulating paper to indicate excursive occlusal contacts. (K. Tamaki et al., 1997, AJ Caro et al., 2005) However, results using articulating paper and wax have been shown to be unreliable (Kerstein RB et al., 2014, Millstein P et al., 2001, Halperin GC et al., 1982, Gazit et al., 1986), often including false-positive marks, and the interpretation of marks on articulating paper can be subjective. (Carossa S et al., 2000, Millstein P et al., 2008) Possible alterations of temporomandibular joint and teeth positions may be caused by the resistance of wax, resulting in inaccurate records of tooth contact by perforated wax. (PL Millstein et al., 1985) Furthermore, contact marks from articulating paper or wax do not indicate occlusal force or changes of occlusal contact during movement, only show the location of the contacts. (Kerstein RB, 2008, Sarah Qadeer et al., 2012, Carey et al., 2007, Saad et al., 2008) The T-scan is a computerized occlusal analysis system developed by Maness and first reported in 1987. (Maness WL et al., 1987) T-scan demonstrates not only static occlusion, like conventional occlusal indicating methods, but also dynamic occlusion and its subsequent factors such as timing and force by displaying changes in occlusal force in real time. (Kerstein RB, 2015, Koos B et al., 2010, Stern K et al., 2010) The T-scan system consists of an intraoral sensor film, a handpiece connected to a computer, and software. The sensor foil is about 100μm thick. (Kerstein RB et al., 2006, Cerna M et al., 2015, Bozhkova TP et al., 2016) The sensor is composed of grid conduction lines that are organized into pressure-sensitive areas called sensels. When occlusal force is applied to the sensor foil the voltage drops, and these changes are analyzed and visualized by the T-scan software. (Koos B et al., 2010, Cerna et al., 2015) The T-scan system has been further advanced over the last 30 years. Since the first T-scan I introduced in 1984, T-scan II for Windows® (1995), T-scan III with turbo recording (2004), and the newly updated T-scan v10 (2018) have been introduced and used. (Kerstein RB, 2015) There were some problems with the initial T-scan I and several studies reported that T-scan I was not accurate and reliable for recording occlusal contacts and bite force due to low-resolution capacity and an excessive variation in sensor sensitivity. (Patyk et al., 1989, ML Hsu, 1992, Lyons MF, 1992) Furthermore, there were issues with non-detectable areas. (Da Silva et al., 2014) The T-Scan II system, however, has been reported to be a reliable method for analyzing and evaluating the occlusal contact distribution in maximum intercuspation.

(Garrido Garcia et al., 1997) As for the T-scan III, it is precise and reliable and is a fast method to record occlusal contacts. (Koos B et al., 2010, Stern K et al., 2010)

The purpose of this study was to evaluate the concordance between semi-adjustable articulator contact and intraoral contact during eccentric movement using T-scan. The concordances of all teeth, working side teeth, and balancing side teeth (anterior and posterior teeth for protrusion) were analyzed. Differences in concordance between intraoral contacts and contacts on the semi-adjustable articulator contacts were analyzed according to direction of mandibular movement and time.

II. MATERIALS AND METHODS

Subjects

Twenty-seven subjects (eleven males and sixteen females) were selected among patients from the Department of Prosthodontics of the Seoul National University Dental Hospital. The subjects were chosen according to the following inclusion criteria: (1) free of signs and symptoms of temporo-mandibular disorder (TMD), (2) no missing teeth (except third molars and premolars for orthodontics), (3) no severe crowding, and (4) no current orthodontic treatment. Exclusion criteria was following: (1) existing sign and symptoms of temporo-mandibular disorder (TMD), (2) presence of missing teeth (except third molars and premolars for orthodontics), (3) severe crowding, and (4) currently receiving orthodontic treatment. Institutional Review Board approval (S-D20170046) was obtained for this study. Informed consent was obtained from all participants. Dental casts, PVS intraoral records, semi-adjustable articulator, and the T-scan were used to evaluate the eccentric movement of the semi-adjustable articulator.

Fabrication of dental casts and mounting

Irreversible hydrocolloid (Aroma Fine Plus Normal set, GC, Tokyo, Japan) impressions of upper and lower arches were taken to create dental stone casts (Snow Rock dental stone, DK MUNGYO Corp., Gimhae, Korea). Before mounting, the maxillary cast was scanned using a model scanner. (T-300, Medit Corp., Seoul, Korea)

The maxillary cast was mounted with plaster (Snow Rock dental plaster, DK MUNGYO Corp., Gimhae, Korea) on the arcon type semi-adjustable articulator (PROTAR Evo 7, Kavo Dental GmbH, Biberach, Germany) using the KaVo ARCUS facebow. The mandibular cast was mounted in maximum intercuspal position without any registration. (Walls AW et al., 1991)

Intraoral records and condylar setting of the articulator

The condylar guidance angle was set using each subject's protrusive record following the manufacturer's instructions. Before taking intraoral records, subjects were instructed to protrude the lower jaw to determine the edge-to-edge relationship of the incisors. (Ecker, 1984, Pelletier, 1991) The Bennettt angle was adjusted using lateral intraoral records. For the laterotrusive record, the subjects were trained to position the mandible to determine a cusp tip-to-cusp tip relationship of the canines in both right and left lateral excursion. (Ecker et al., 1984, Pelletier et al., 1991) Protrusive and lateral intraoral records of all subjects were taken using polyvinyl siloxane impression material. (O-bite, DMG, Hamburg, Germany) After setting the horizontal and lateral condylar guidance angles, eccentric mandibular movements on the articulator were recorded using T-scan.

Recording eccentric occlusal contacts with the T-scan

Subjects were seated on a dental chair, and the average width of two maxillary central incisors was measured. Missing teeth were noted, and the measurement was input to T-scan v9.1 (T-scan, Tekscan Inc., South Boston, USA) to customize the arch size. T-scan automatically determines the average value for tooth width. After the arch size was defined, the sensor support's position guide was placed between the central incisors, and the handle was kept as parallel to the occlusal plane as possible, according to the manufacturer’s recommendations. Before recording, a pre-test was conducted by asking the subject to close their jaw three times, and the sensitivity was adjusted until 1-3 pink sensels were shown, based on the manufacturer’s recommendations. Each recording included two eccentric cycles. Recordings were conducted three times each to the right, left, and protrusive mandibular movement. The same procedure was performed using the articulator.

Comparison of occlusal contacts

The stereolithography(STL) files of the maxillary cast were aligned to the arch for each subject. The interocclusal record from maximum intercuspation was used as a reference for positioning the STL file. After positioning the STL file, the arch was divided into individual teeth. Of the two eccentric cycles, the cycle showing greater occlusal force was chosen for analyses. T-scan depicts occlusal force changes over time as a graph, and the force graph was marked with four vertical lines denoted A, B, C, and D. A to B indicates occlusion time and C to D indicates disclusion time.

According to the manufacturer's protocols, occlusion time is defined as the time elapsed from the first tooth contact until the last tooth contact, and disclusion time is defined as the time elapsed since the beginning of a jaw movement made in one direction until only the canine or incisors are in contact. Since the T-scan defines the D line based on anterior guidance, the D line was adjusted by the examiner to the point when the non-working side was completely separated. As this study was focused on evaluating eccentric mandibular movements, the C line was defined as T0 and the D line was defined as T3. The time point halfway between C and D was considered T1, and that three-quarters of the way between C and D was considered T2. (Figure 1) The time point one-quarter of the way between C and D was not included in the analysis to better concentrate on the eccentric position. At each time point, the relative occlusal force of the teeth was recorded. Figure 2(A) through Figure 3(D) show T0, T1, T2, and T3 for the mandible and articulator on the right excursion.

Relative occlusal force measurements by the T-scan were repeated three times and averaged. Any occlusal force data detected was assumed to indicate the presence of occlusal contact, which was scored as "1". If not, it was scored as "0". The concordances of intraoral occlusal contacts and articulator occlusal contacts were calculated at T0, T1, T2, and T3. The concordances of all teeth, working side, and balancing side (anterior and posterior teeth for protrusion) were calculated. Differences in concordance between contacts on the semi-adjustable articulator and intraoral contacts were analyzed according to the direction of mandibular movement and time. The discrepancies between intraoral and articulator contacts on the working and balancing sides were sorted into two categories, positive occlusal error and negative occlusal error. (Hobo et al., 1976)

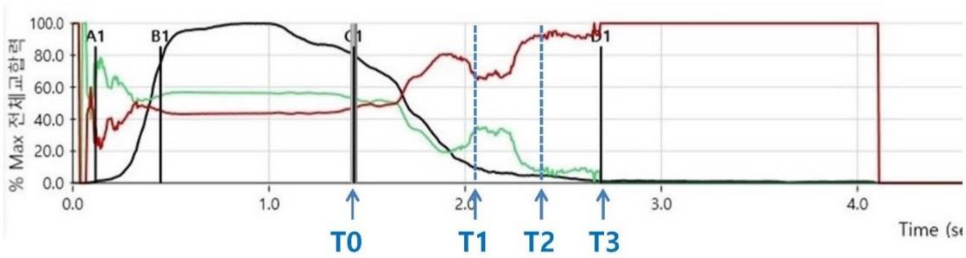

Figure 1. **Occlusal force changes over time.** T0 represents the beginning of a jaw movement made in one direction and T3 is the time point when the teeth on the non-working side for right and left excursion and posterior teeth for protrusion were completely separated. The time point halfway between T0 and T3 was defined as T1 and that three-quarters between T0 and T3 was defined as T2.

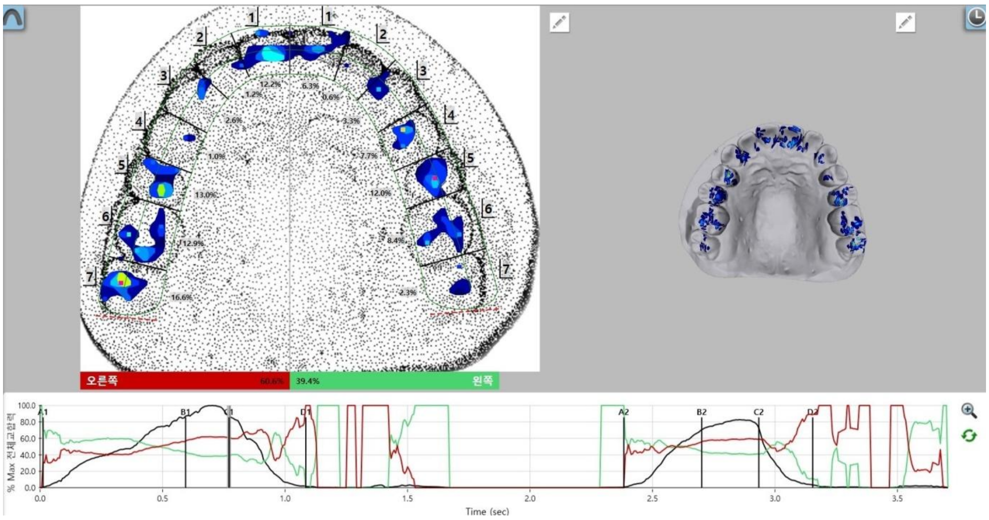

Figure 2(A). Right excursion on the articulator at T0.

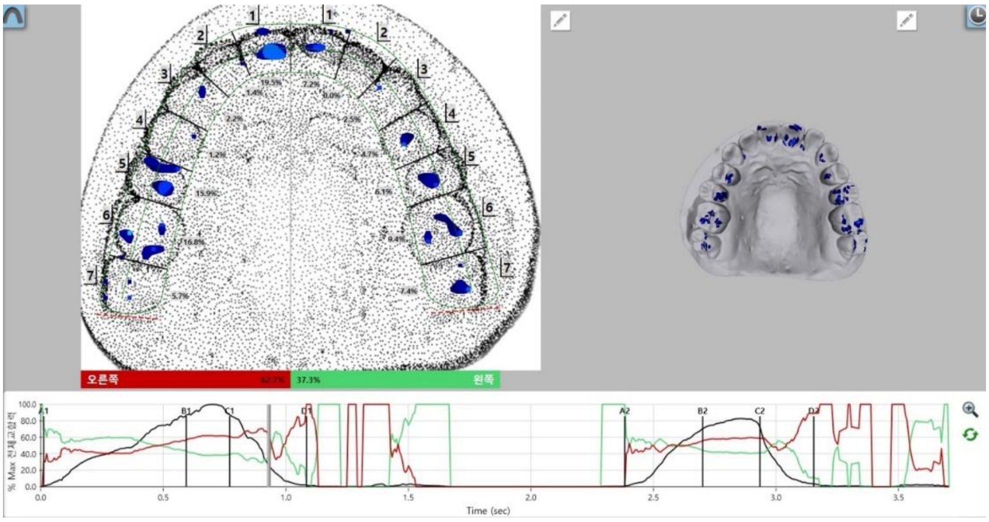

Figure 2(B). Right excursion on the articulator at T1.

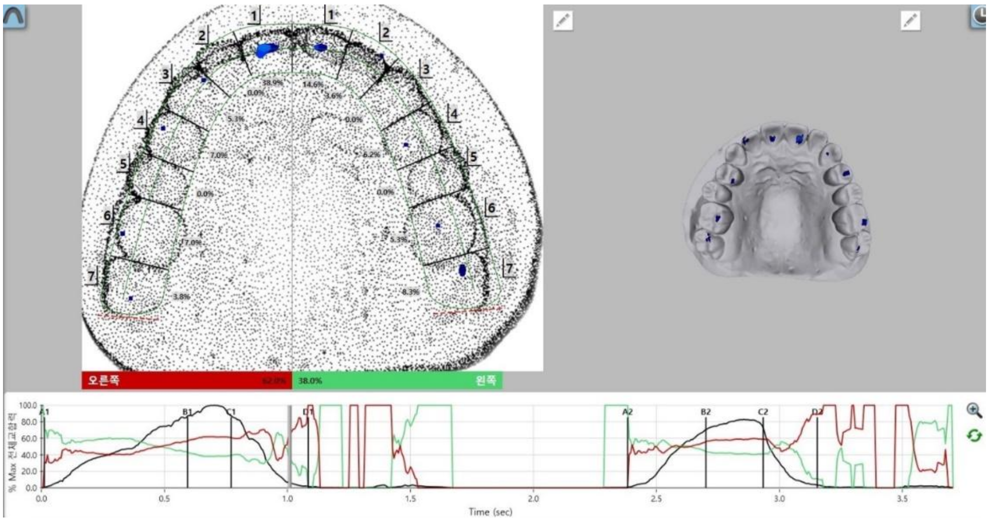

Figure 2(C). Right excursion on the articulator at T2.

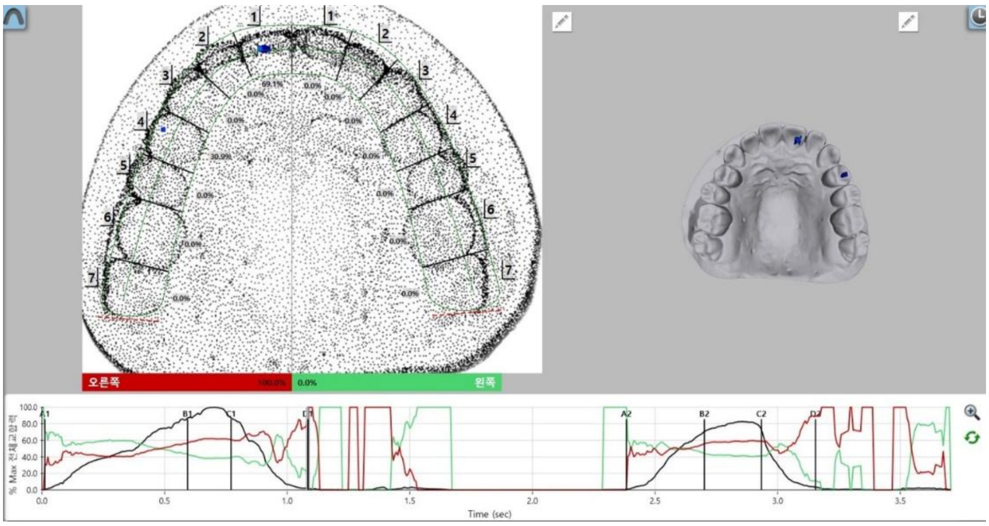

Figure 2(D). Right excursion on the articulator at T3.

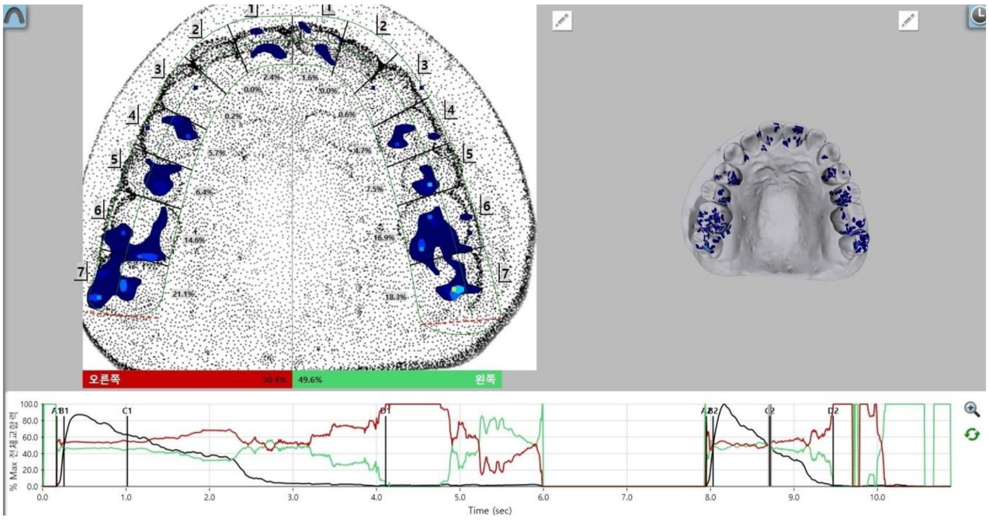

Figure 3(A). Right excursion of the mandible at T0.

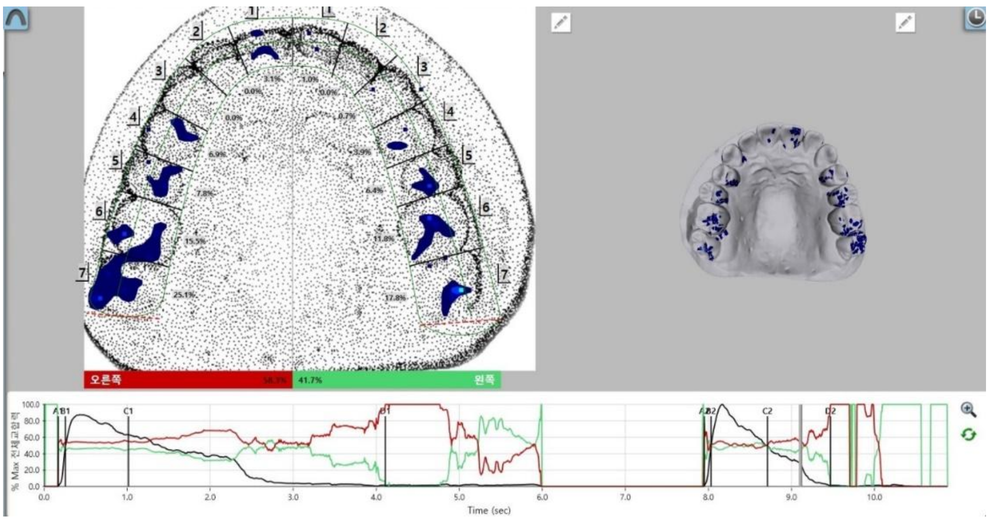

Figure 3(B). Right excursion of the mandible at T1.

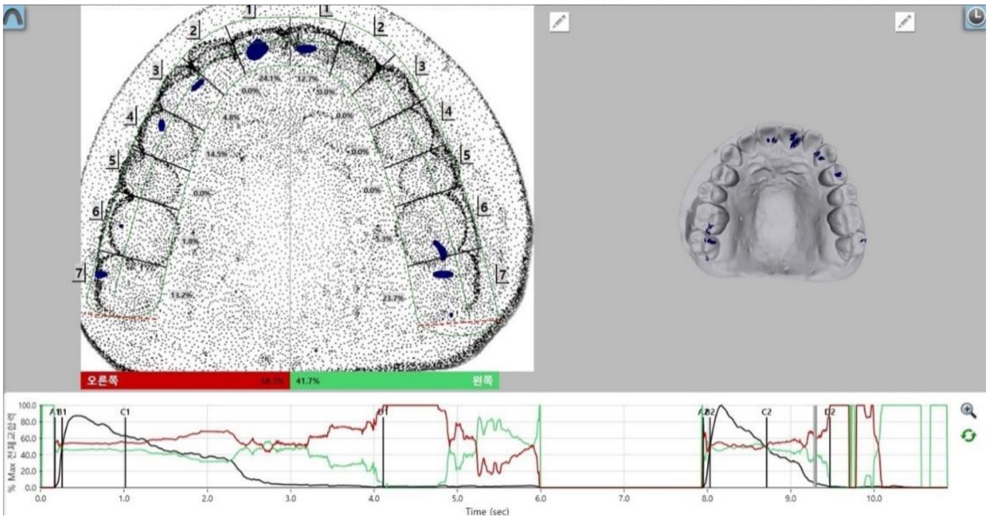

Figure 3(C). Right excursion of the mandible at T2.

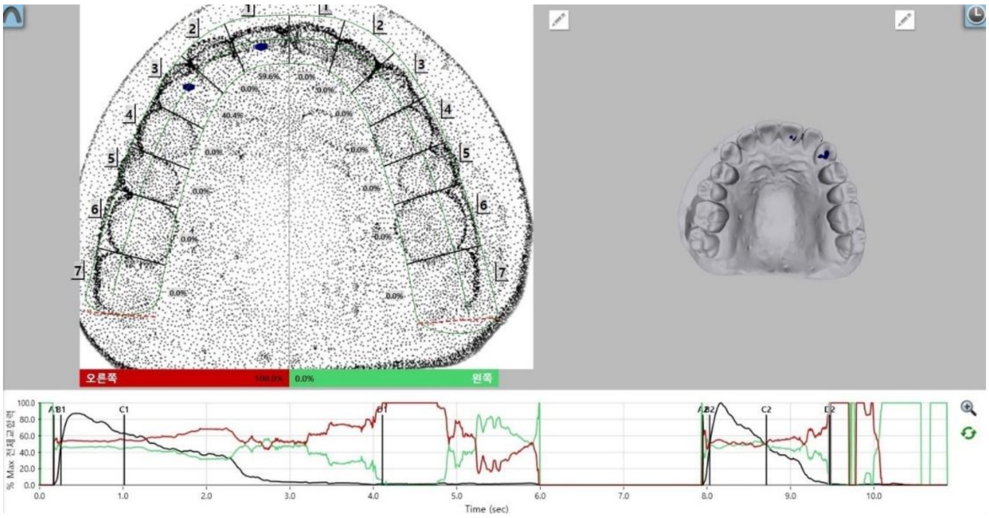

Figure 3(D). Right excursion of the mandible at T3.

Statistical analysis

Paired *t*-tests were used to examine differences between left and right horizontal and lateral condylar guidance angles. Intraclass correlation coefficients (ICC) were used to evaluate the reproducibility of repeated tests. To calculate ICC, one tooth among 16 maxillary teeth of each subject was randomly selected. It was repeated 16 times and the average was called level 1 ICC. Also, level 1 ICC was calculated repeatedly ten times and the average of it was named Level2 ICC. Level2 ICC was used to evaluate the reproducibility of repeated tests. Repeated measures analysis of variance (RM-ANOVA) was used to analyze factors affecting concordances between intraoral and articulator contacts. After RM-ANOVA, Bonferroni post hoc tests were used to examine the statistically significant differences. All statistical analyses were conducted at the confidence level of 99%.

III. RESULTS

Condylar guidance angle

The mean horizontal condylar guidance angles of twenty-seven subjects obtained by the check bite method were 46.8±9.6° for the right side and 46.3±8.6° for the left side. The mean lateral condylar guidance angles (Bennett angle) were 5.4±2.0° for the right side and 6.9±5.8° for the left side. (Table 1) There were no significant differences in horizontal and lateral condylar guidance angles between the right and left sides.

Table 1. Mean horizontal and lateral condylar guidance angles(°)

	Horizontal condylar guidance angle		**Lateral condylar guidance angle (Bennett angle)**	
	Right	**Left**	**Right**	**Left**
Average	46.8	46.3	5.4	6.9
Standard deviation	9.6	8.6	2.0	5.8

Concordance between intraoral and articulator contacts

For all teeth, concordance between intraoral occlusal contacts and articulator contacts during excursive mandibular movement was highest at T0, showed a decreasing tendency at T1 and T2, and increased slightly at T3. (Table 2, Figure 2(A)-Figure 2(C)) Concordances between intraoral and articulator occlusal contacts of all teeth at T3 were 85.2±10.4% on the right excursion, 85.0±9.4% on the left excursion, and 85.7±11.1% on the protrusive excursion. There were no statistically significant differences among the concordances of right lateral, left lateral, and protrusive excursion. However, there were statistically significant differences among concordance values regarding timelines of excursive movement. (Table 3) The concordances on right, left and protrusive excursion at T3 were lower than the concordances at T0, but the differences were not statistically significant

When comparing the working and balancing sides of lateral excursion, the concordances between intraoral occlusal contacts and articulator contacts during excursive mandibular movement on the working side were similar to the concordances at T0 on the balancing side and were statistically significantly lower than the balancing side concordances at T3. (Table 4, Table 5, Figure 5(A), 5(B)) Anterior teeth showed statistically significantly lower concordance than posterior teeth during protrusive excursion at T0 and T3. (Table 4, Figure 5(C))

The average concordances of the working side at T3 were 72.7±20.7% on the right excursion and 72.5±18.7% on the left excursion. The discrepancies of the working side concordances at T3 were 27.34% on the right excursion and 27.53% on the left excursion. Among the discrepancies of the working side concordances at T3 on the right excursion, the rate of positive occlusal error was 18.10% (66.2% of the total working side discrepancy) and the rate of negative occlusal error was 9.24% (33.8% of the total working side discrepancy). Among the discrepancies of the working side concordances at T3 on the left excursion, the rate of positive occlusal error was 15.49% (56.3% of the total working side discrepancy) and the rate of negative occlusal error was 12.04% (43.7% of the total working side discrepancy). The discrepancies of the balancing side concordances at T3 were 2.58% on the right excursion and 2.65% on the left excursion. Among the discrepancies of the balancing side concordances at T3 on the right excursion, the rate of positive occlusal error was 1.72% (66.7% of the total balancing side discrepancy) and the rate of negative occlusal error was 0.86% (33.3% of the total balancing side discrepancy). On the left excursion, the rate of positive occlusal error was 2.12% (80.0% of the total balancing side discrepancy) and the rate of negative occlusal error was 0.53% (20.0% of the total balancing side discrepancy). The discrepancies of the concordances at T3 on the protrusive excursion were 27.78% for the anterior teeth and 5.27% for the posterior teeth. Among the discrepancies of the anterior concordances at T3 on the protrusive excursion, the rate of positive occlusal error was 14.62% (52.6% of the total anterior discrepancy) and the rate of negative occlusal error was 13.16% (47.4% of the total anterior discrepancy). For the posterior teeth, the rate of positive occlusal error was 2.63% (50.0% of the total posterior discrepancy) and the rate of negative occlusal error was 2.63% (50.0% of the total posterior discrepancy). (Table 6)

Table 2. Concordances between intraoral and articulator occlusal contacts of all teeth during excursive movements

All teeth	Right	Left	Protrusion
T0	90.8 ± 7.4%	90.9 ± 9.8 %	92.3 ± 10.1 %
T1	77.1 ± 15.1 %	77.2 ± 10.8 %	79.1 ± 14.3 %
T2	72.5 ± 13.0 %	70.9 ± 13.2 %	64.5 ± 12.9 %
T3	85.2 ± 10.4 %	85.0 ± 9.4 %	85.7 ± 11.1 %

Table 3. Statistical differences of concordances between intraoral and articulator occlusal contacts according to the direction of mandibular movement and time using two-way RM-ANOVA

Factor	***P*** **-value**	Significance (α = 0.01)
Time	< 0.0001	Significant
LRP	0.8524	No Significance
Time*LRP	0.2106	No Significance

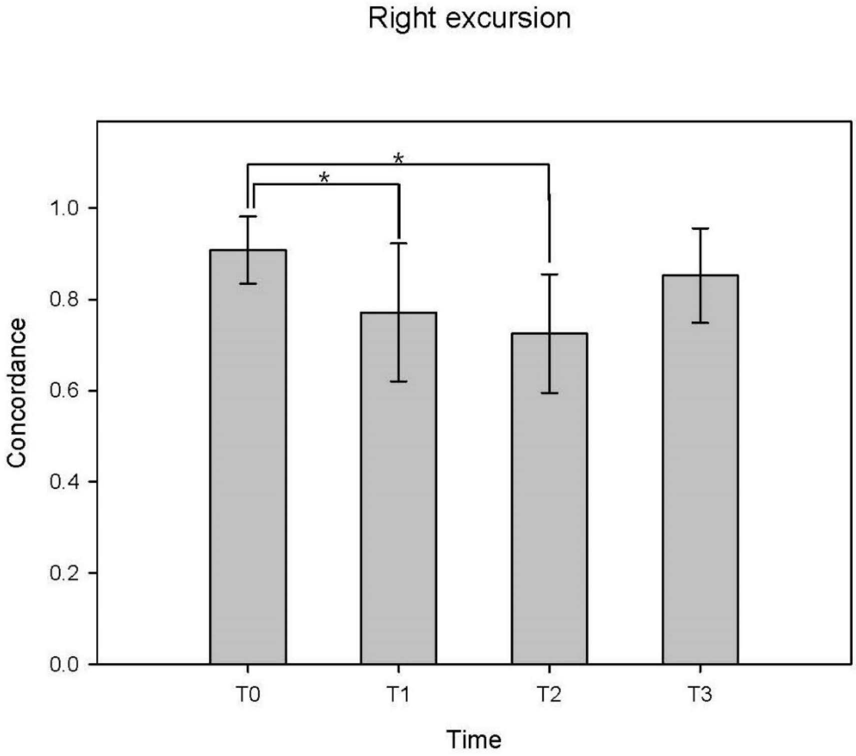

Figure 4 (A). Concordances between intraoral and articulator occlusal contacts of all teeth on the right excursion. * indicates groups statistically significantly different.
* : $P \leq 0.01$

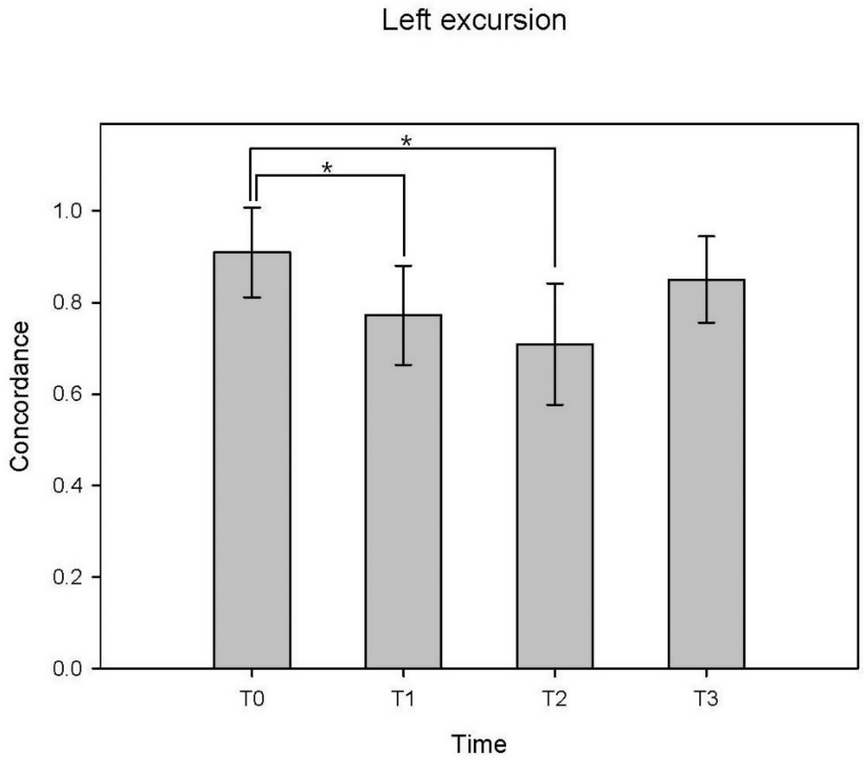

Figure 4(B). Concordances between intraoral and articulator occlusal contacts of all teeth on the left excursion. * indicates groups statistically significantly different.
***** : $P \leq 0.01$

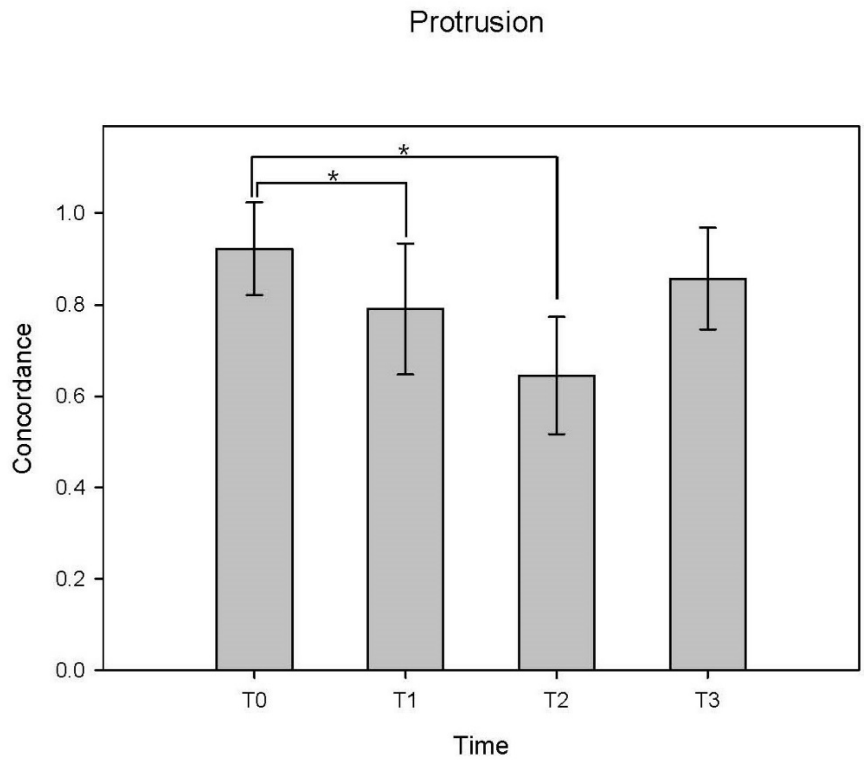

Figure 4(C). Concordances between intraoral and articulator occlusal contacts of all teeth during protrusive excursion. * indicates groups statistically significantly different. * : $P \leq 0.01$

Table 4. Concordances between intraoral and articulator occlusal contacts of working side and balancing side teeth during excursive movements

	Right		Left		Protrusion	
	Working	**Balancing**	**Working**	**Balancing**	**Anterior**	**Posterior**
T0	91.2±8.5 %	90.4±10.6%	90.4±11.3%	91.6±12.8%	85.8±20.1%	96.5±8.0%
T1	81.7±17.1%	72.7±21.0%	83.7±15.3%	70.9±19.3%	72.8±23.6%	83.2±16.7%
T2	75.4±19.4%	69.5±18.5%	74.4±18.9%	67.5±19.5%	69.1±18.0%	60.5±15.2%
T3	72.7±20.7%	97.4±5.4%	72.5±18.7%	97.4±6.8%	72.2±21.8%	94.7±8.0%

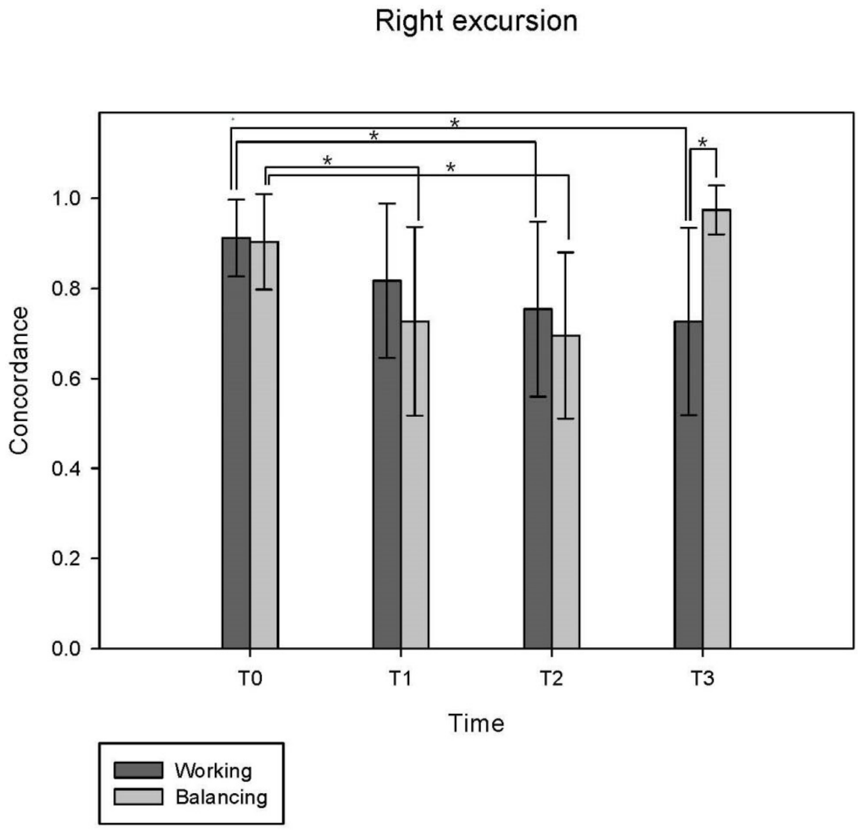

Figure 5 (A). Concordances between intraoral and articulator occlusal contacts of working side and balancing side teeth on the right excursion. * indicates groups statistically significantly different. * : $P \leq 0.01$

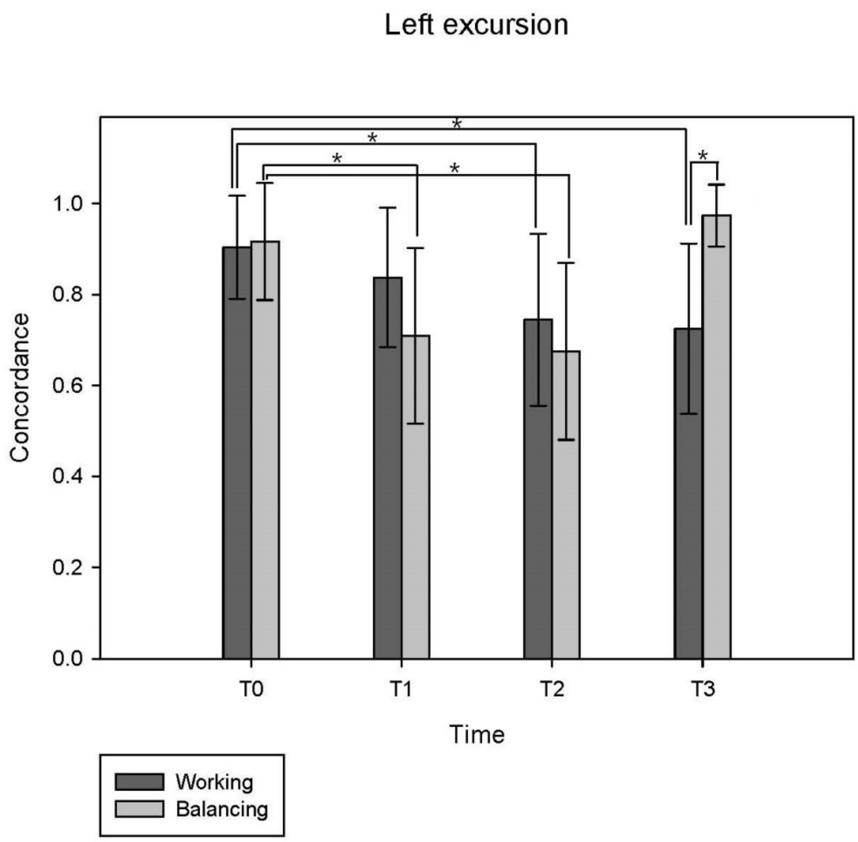

Figure 5(B). Concordances between intraoral and articulator occlusal contacts of working side and balancing side teeth on the right excursion. * indicates groups statistically significantly different. * : $P \leq 0.01$

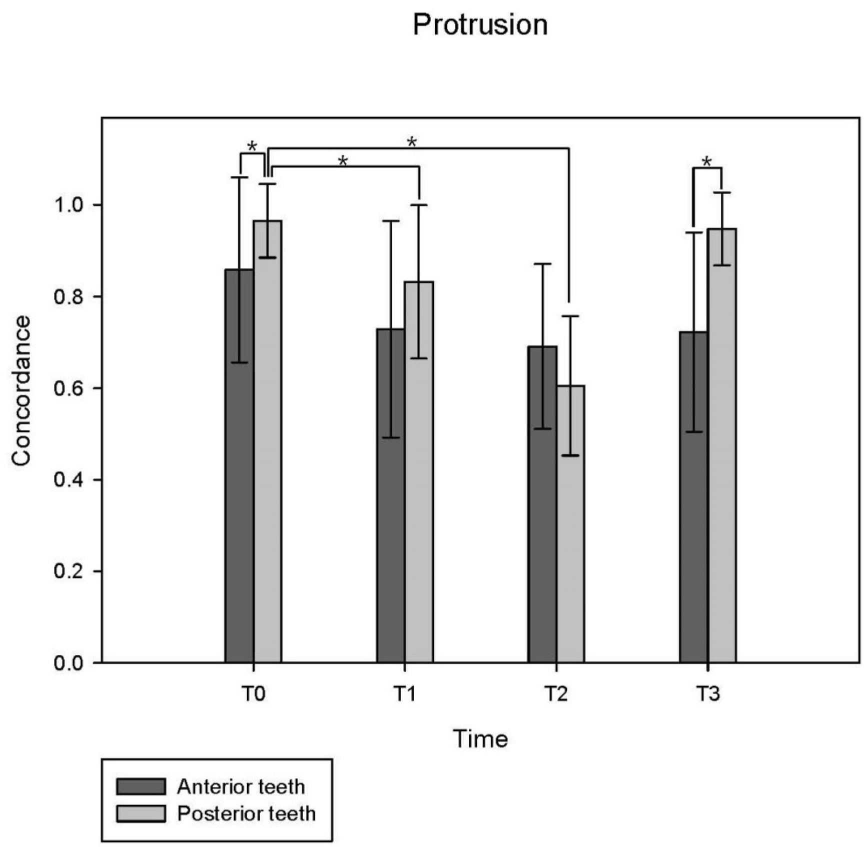

Figure 5(C). Concordances between intraoral and articulator occlusal contacts of working side and balancing side teeth during protrusive excursion. * indicates groups statistically significantly different. * : $P \leq 0.01$

Table 5. Statistical differences of concordances between intraoral and articulator occlusal contacts according to the direction of mandibular movement, time, and working and balancing side using three-way RM-ANOVA

Factor	***P*-value**	**Significance (α = 0.01)**
Time	< 0.0001	Significant
W/B	0.0051	Significant
LRP	0.5917	No Significance
Time*W/B	< 0.0001	Significant
Time*LRP	0.4719	No Significance
W/B*LRP	0.1709	No Significance
Time*W/B*LRP	0.0956	No Significance

Table 6. The rate of positive and negative occlusal error at T3 for the excursive movement; (%) value means the rate of total discrepancy

	Right		**Left**		**Protrusion**	
	Working	**Balancing**	**Working**	**Balancing**	**Anterior**	**Posterior**
Positive error	18.10% (66.2%)	1.72% (66.7%)	15.49% (56.3%)	2.12% (80.0%)	14.62% (52.6%)	2.63% (50.0%)
Negative error	9.24% (33.8%)	0.86% (33.3%)	12.04% (43.7%)	0.53% (20.0%)	13.16% (47.4%)	2.63% (50.0%)
Total	27.34% (100%)	2.58% (100%)	27.53% (100%)	2.65% (100%)	27.78% (100%)	5.27% (100%)

Reproducibility of repeated tests

The reproducibility of three repeated tests of mandibular eccentric movement made by T-scan is shown on Table 5. ICCs between 0.5 and 0.75 were considered to indicate moderate reliability, 0.75 and 0.9 good reliability, and greater than 0.9 excellent reliability. (Koo TK et al., 2016) All ICC values of eccentric movements measured by T-scan showed better than moderate reliability. ICC values at T0 and T3 showed better than good reliability. Except for the left excursion at T3, most ICC values for the mandible were higher than those for the articulator. (Table 7)

Table 7. Intraclass correlation coefficients of repeated excusive movements using T-scan

Excursion	Time	Measurement	ICC	SD
Left	T0	Mandible	0.966125	0.000798
Left	T0	Articulator	0.86703	0.004217
Left	T1	Mandible	0.851892	0.009966
Left	T1	Articulator	0.629457	0.010771
Left	T2	Mandible	0.782699	0.016922
Left	T2	Articulator	0.72058	0.020997
Left	T3	Mandible	0.812528	0.023509
Left	T3	Articulator	0.895934	0.016091
Right	T0	Mandible	0.95996	0.001646
Right	T0	Articulator	0.879825	0.003431
Right	T1	Mandible	0.815539	0.011186
Right	T1	Articulator	0.679682	0.018451
Right	T2	Mandible	0.774579	0.010636
Right	T2	Articulator	0.745401	0.017637
Right	T3	Mandible	0.843603	0.014069
Right	T3	Articulator	0.763803	0.027704
Protrusion	T0	Mandible	0.959852	0.001554
Protrusion	T0	Articulator	0.755861	0.006507
Protrusion	T1	Mandible	0.762664	0.011103
Protrusion	T1	Articulator	0.648719	0.020189
Protrusion	T2	Mandible	0.645117	0.018796
Protrusion	T2	Articulator	0.616442	0.02264
Protrusion	T3	Mandible	0.814127	0.016508
Protrusion	T3	Articulator	0.773107	0.018678

IV. DISCUSSION

The eccentric mandibular movements on a semi-adjustable articulator were evaluated by T-scan in this study. Concordances between intraoral occlusal contact and articulator occlusal contact were significantly different over time, meaning that concordance changed during excursive mandibular movements. Concordances of all teeth at T3 were 85.2% during right lateral excursive movements, 85.0% during left excursive movement, and 85.7% during protrusive excursive movement. However, the concordances of the working side at T3 were 72.7% on the right excursion and 72.5% on the left excursion, and the concordance of anterior teeth at T3 was 72.2% on the protrusive excursion. Concordances of the working side (for right and left excursion) and anterior teeth (for protrusive excursion) at T3 were statistically significantly lower than those of the balancing side (for right and left excursion) and posterior teeth (for protrusive excursion). This indicates discrepancies for the guiding teeth. Comparing concordances of working side teeth on the lateral excursion at T0 and T3, T3 revealed statistically significantly lower concordance, indicating lower concordance within guiding teeth when the balancing side teeth were discluded during lateral eccentric movement than when the occlusion was closer to maximum intercuspation.

As the Frankfort plane was set as the reference plane, the horizontal condylar guidance angle was 40-50° in a previous study. (Olsson A, 1961) The mean horizontal condylar guidance angles in this study were 46.8° on the right and 46.3° on the left, similar to the previous study.

Tamaki et al. analyzed the reproduction of excusive tooth contacts by an articulator set up with computerized axiography. The articulator reproduced 82% of the protrusive tooth contacts and 90% of the laterotrusive tooth contacts, up to movements of 4mm. (K. Tamaki, 1997) In the previous study, the condylar guidance angle was determined with axiography which results in less variation than the intraoral record, and occlusogram wax was used to analyze occlusal contacts. (Price RB, 1988, dos Santos et al., 2003) Tamaki et al. concluded that the ability of the articulator to simulate excursive tooth contacts was limited. In this study, concordances of all teeth at T3 were 85.2% on the right, 85.0% on the left, and 85.7% on the protrusive excursion, similar to the previous study.

Caro et al. noted that concordances vary between intraoral contacts and articulator contacts depending on the type of lateral guidance used. When the condylar guidance angle was defined by the protrusive intraoral record using wax, the concordances between intraoral contacts and articulator contacts were 82% with canine guidance, 40% with anterior guidance, and 0% with group function. When using axiography to determine the condylar guidance angle, the concordances between intraoral and articulator contacts were 100% with canine guidance, 80% with anterior guidance, and 60% with group function. Concordances were higher using axiography than when using intraoral record. (Caro AJ et al., 2005) In this study, the concordances of all teeth between intraoral contacts and contacts on the articulator were 85.2% on the right excursion and 85.0% on the left excursion, which are higher values than those found in the previous study. However, only 17 subjects were included in that study. In addition, only the first 2mm of gliding movement of the mandible to the right and left (equivalent to T1 or T2) was recorded in the previous study, whereas our subjects executed maximal mandibular excursions in this study. Concordances of whole teeth were 77.1% on the right, 77.2% on the left, and 79.1% on the protrusive excursion at T1 and 72.5% on the right, 70.9% on the left, and 64.5% on the protrusive excursion at T2. Furthermore, the previous study used 40μm articulating paper as the occlusal indicator and wax as protrusive intraoral recording material. False-positive marks are often seen when using articulating papers, and saliva can affect contact marks. (Saracoglu A et al., 2002, Kerstein RB et al., 2014, Millstein P et al., 2001, Halperin GC et al., 1982, Gazit et al., 1986) In addition, contact marks from articulating papers do not indicate occlusal force or changes of occlusal contacts over time, and wax is known as the most inaccurate interocclusal record materials because of its high coefficient of thermal expansion and high resistance to closure. (Camposs AA et al., 1999, Mullick SC et al., 1981, Fattore L et al., 1984, Millstein PL et al., 1971, Millstein PL et al., 1973, Millstein PL et al., 1983, Millstein PL et al., 1985, Lassila V, 1986) In this study, PVS material was used as the intraoral record because of its minimal resistance to closure, dimensional stability, and rigidity after setting. (Chee WW, 1992, Mandikos MN, 1998, Millstein PL et al., 1994, Campos AA et al., 1999) Furthermore, the T-scan was used as occlusal indicator, as it is known to be precise and reliable for recording occlusal contacts and shows not only static occlusion but also the transition of occlusal force and contact over time. (Koos B et al., 2010, Stern K et al., 2010, Jeong MY et al., 2020)

Using the T-scan, concordances were significantly lower at T3 than T0 in working side teeth on right and left excursion. That is, an articulator could not simulate the working side precisely during lateral excursion. This lack might arise from the linear property of the condylar guidance structure on the semi-adjustable articulator. Although the Bennett angle was set up with laterotrusive record, Bennett movement was reproduced into only linear movement. Moreover, the immediate side shift could not be adjusted precisely on the semi-adjustable articulator. These structural limitations of the semi-adjustable articulator might cause significantly lower concordance of the working side during lateral excursive movement. Furthermore, at T3, there were discrepancies in working side (for right and left) and anterior teeth (for protrusion) concordances of 27.34% on the right, 27.53% on the left, and 27.78% on the protrusive excursion. Hobo et al. classified occlusal errors while using an articulator. A positive occlusal error is seen when the articulator undercompensates for mandibular movement and a negative occlusal error is seen when the articulator overcompensates for mandibular movement. (Hobo et al., 1976) Among discrepancies of concordances between intraoral contacts and articulator contacts, positive occlusal errors of the working side (for right and left excursion) and anterior teeth (for protrusive excursion) were 18.10% on the right, 15.49% on the left, and 14.62% on the protrusive excursion. Consequently, occlusal adjustment of the working side may be necessary after the delivery of a prosthesis. Meanwhile, there were discrepancies in the balancing side (for right and left) and posterior teeth (for protrusion) concordances at T3 of 2.58% on the right, 2.65% on the left, and 5.27% on the protrusive excursion. Among discrepancies of the balancing side (for right and left excursion) and posterior teeth (for protrusive excursion) concordances, positive occlusal errors were 1.72% on the right, 2.12% on the left, and 2.63% on the protrusive excursion. The possibility that occlusal adjustment of the balancing side may be necessary after delivery of a prosthesis should be kept in mind, since occlusal interference on the balancing side is destructive and might cause condylar movements and temporo-mandibular disorders. (Hobo et al., 1976, Ramfjord SP et al., 1961, Solberg WK et al., 1979, Mohlin B et al., 1978, Morita T et al., 2016) The reproducibilities of three repeated tests of mandibular eccentric movement using the T-scan were better than good at T0 and T3. ICC values were lower on the articulator than on the mandible most of the time. As an articulator is an instrument with joints, its movement can vary according to the applied force. Accordingly, clinicians and dental technicians should be careful while operating articulators.

This study was conducted using T-scan because T-scan can show changes in occlusal contacts in real time. However, the T-scan system has limitations including unstable sensitivity and alterations of occlusion. Da Silva et al. reported that the surface of the T-scan sensor film does not always show uniform sensitivity. (Da Silva M et al., 2014) It has been reported that the direction of the mandible upon closing can be shifted by the sensor film of the T-scan, therefore the occlusal contact force and occlusal contact points may be detected inaccurately. (Beninati CJ et al., 2019, Mitchem JA et al., 2017) Furthermore, Jeong et al. reported that some regions of the sensor films can malfunction, which was confirmed by regions showing positive signal even though no force was applied. This phenomenon was also observed in the present study. This could occur due to manufacturing error or tearing of the sensor film during excursion. Meanwhile, the check bite method was used to determine the condylar guidance angle. However, the check bite method have been found to be neither accurate nor reproducible in previous study. (Pelletier LB et al., 1991, Posselt UP et al., 1960, Gross M et al., 1990, Gross M et al., 1998) In the present study, PVS material was used for the intraoral record because of its minimal resistance to closure, dimensional stability, and rigidity after setting. (Chee WW et al., 1992, Mandikos MN, 1998, Millstein PL, 1994, Campos AA et al., 1999) Further studies using extraoral devices to determine the condylar guidance angle are needed to evaluate the semi-adjustable articulator more accurately.

V. CONCLUSION

As a result of assessment of the concordance between semi-adjustable articulator contact and intraoral contact during eccentric movement using T-scan, the concordance changed during excursive mandibular movements.

When comparing intraoral contact with articulator contact during lateral eccentric mandibular movement, the concordances of the working side were significantly lower at the completion of eccentric movement than at the beginning of jaw movement. Occlusal adjustment of the working side might be required after the delivery of a prosthesis.

When the balancing side (for lateral excursion) or posterior teeth (for protrusive excursion) were discluded, there were positive occlusal errors. Although these values are low, the possibility that occlusal adjustment of the balancing side might be necessary after the delivery of a prosthesis should be kept in mind.

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– 국문초록 –

반조절성 교합기에서 T-scan 을 이용한 편심위 교합 접촉의 재현성

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정 민 영

목 적 : 교합기는 진단과, 수복과정에 있어서 석고 모형을 이용하여 교합접촉을 재현하기 위해 사용된다. 반조절성 교합기의 하악 운동 경로에 대한 연구들은 오래 전부터 보고되어 왔지만, 구강 내에서의 하악의 편심위 운동과 반조절성 교합기에서의 편심위 운동에서 치아 접촉을 비교하는 연구는 부족하다. 본 연구의 목적은 디지털 교합측정 기기인 T-scan 을 이용하여 반조절성 교합기와 구강 내에서 하악의 편심위 운동시의 치아 접촉을 비교하는 것이다.

방 법 : 턱관절 질환이 없고, 교정 발치 및 제 3 대구치를 제외한 치아의 상실이 없으며, 심한 총생이 없고 현재 교정치료를 받고 있지 않는 27 명의 피험자(남자 11 명, 여자 16 명)에서 T-scan 을 이용하여 구강 내에서 하악의 편심위 운동(전방, 우측방, 좌측방)을 3 회 반복했다. 피험자에서

비가역성 수성콜로이드인상채득으로 얻어진 석고 모형을 안궁이전을 통해 마운팅하고, 부가중합형 실리콘 체크바이트를 이용하여 반조절성 교합기인 Kavo 7 PROTARevo 의 과로각을 설정한 후, T-scan 을 이용하여 교합기에서 하악의 편심위 운동(전방, 우측방, 좌측방)을 3 회 반복했다. 이후, T-scan 소프트웨어에서 교합점을 정확하게 위치시키기 위하여 상악 석고 모형을 모델스캐너에서 스캔하여 얻은 Stereolithography(STL) 파일을 T-scan 소프트웨어에서 교합점과 중첩시킨 후, 각 치아 별 상대적 교합력을 이용하여 3 회 반복의 재현성을 평가하였다. T-scan 소프트웨어에서 표기된 이개가 시작되는 시점인 C 지점을 T0, 이개가 완료된 시점인 D 를 T3, 그 중간인 1/2 시점과 3/4 시점을 T1, T2 로 하여, 구강 내와 반조절성 교합기에서 하악의 편심위 운동에서의 교합접촉을 시간의 흐름에 따라 분석하여 그 차이를 비교하였다. 일치도 평가 시에는 3 반복한 데이터의 평균을 이용하여, 교합점의 유무로 일치도를 평가하였다. 좌, 우측 측방 편심위 이동의 경우 작업측과 비작업측, 전방 편심위 이동의 경우 전치부와 구치부로 나누어 시간에 따른 일치도를 분석하였다. 반복 재현성의 평가는 급내 상관 계수를 이용하였고, 평균데이터를 이용한 일치도의 평가는 이원 반복 분산 분석와 삼원 반복 분산 분석을 이용하였으며, 이후 본페로니 사후검정을 진행하였다.

결 과 : 27 명의 시상과로각은 우측 평균 46.8±9.6 도, 좌측 평균 46.3±8.6 도, 측방과로각은 우측 평균 5.4±2.0 도, 좌측 평균 6.9±5.8 도의 값을 보였다. 구강내와 반조절성 교합기의 하악 측방 편심위

운동 시 교합접촉의 일치도를 비교했을 때, 우측, 좌측으로 이개되기 시작하는 시점(T0)에서는 90% 이상의 높은 일치도를 보였으며, 완전히 편심위로 이동했을 때(T3) 작업측에서 유의하게 낮은 일치도를 보였다. 반조절성 교합기에서 우측, 좌측, 전방 이동에서 완전히 편심위로 이동했을 때, 우측, 좌측 이동 시 비작업측에서 각각 2.58%, 2.65%, 전방 이동에서는 구치부에서 5.27%의 불일치가 관찰되었다. 이 중 양형 교합 오류는 우측 편심위 이동시 1.72%, 좌측 편심히 이동시 2.12%, 전방 편심위 이동시 2.63%로 관찰되었다. T-scan 을 통한 구강내와 교합기의 반복 재현성을 분석했을 때, 좌측 편심위의 T3 시점을 제외하고는 구강내에서 좀 더 높은 재현성을 보였다.

결 론 : 반조절성 교합기와 구강 내의 교합점 일치도를 시간에 따라, 하악 편심위 운동 방향에 따라 평가한 결과, 시간에 따라 교합점 일치도가 달라짐을 볼 수 있었다. 하악 측방 편심위 운동 시, 구강 내와 반조절성 교합기의 작업측 교합점 일치도를 비교했을 때, T0 시점보다 T3 시점에서 유의하게 낮은 값을 보이므로, 보철물을 구강 내에 적합 이후 작업측 교합조정을 요할 수 있다. 반조절성 교합기에서 하악 편심위 운동 시, 구강 내와 반조절성 교합기의 비작업측 교합점 일치도를 비교했을 때, T3 시점에서 1.7~2.6%의 양형 교합 오류가 관찰되며, 이는 적은 양이지만 교합기의 과보상으로 해결되지 않으므로 보철물 적합 이후 구강 내에서 비작업측의 조절 가능성을 염두에 두어야 한다.

주요어 : 반조절성 교합기, T-scan, 편심위 치아 접촉, 체크바이트, 교합접촉
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