CASE REPORT

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Post-operative optimization of gum-chewing kinematics in a prognathic patient

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Abstract
Smooth jaw movements during gum chewing, which are defined as those driven by optimally smooth patterns of temporal change in acceleration/deceleration, have been quantified in subjects with acceptable occlusions. This paper reports a case in which significant improvement of the smoothness of masticatory jaw movement was observed following surgical-orthodontic treatment. A patient, who demonstrated a mandibular prognathism, underwent the treatment. The irregularity in acceleration/deceleration of jaw closing movement during gum chewing was quantified by the movement jerk-cost, where the jerk is rate of change in movement acceleration/deceleration. The normalized jerk-costs and results of maximum-smoothness model simulation were compared between jaw movements at pre- and post-treatment stages. The correction of mandibular prognathism and crossbite allowed the patient to close the jaw with wider lateral excursion. Furthermore, smoothness of the jaw closing movements increased significantly and the velocity profile was characterized as similar to that predicted by the kinematic model after treatment. These findings for achievement of 'functional occlusion' that allows the patient to perform smooth and economical jaw closing movements during chewing demonstrate necessity of orthodontic treatment of mandibular prognathism to improve jaw motor function.

Key words: chewing; jaw movement; optimization; orthodontic treatment; treatment outcome

Introduction

It has been demonstrated that kinematic optimality of masticatory cycle (1–4) and efficient occlusal contact area (5, 6) between upper and lower teeth give mechanical advantages to reduction of food particle size. Also, it should be noted that masticatory jaw movements are controlled depending on occlusal condition (7–9). Accordingly, an achievement of 'functional occlusion (10)' that may allow efficient masticatory jaw movement is one of the crucial goals of orthodontic treatment.

Smoothness of human body movements has been defined as optimal simplicity of temporal changes in the movement acceleration/deceleration (11–14). Thus, the less smooth movements have been defined as those driven by complex patterns of acceleration/deceleration. Validity of measurements for movement irregularity in terms of movement jerk has been verified in diagnosis of human jaw (11, 12), arm (13) and eye (14) movements, where the jerk is rate of change in movement acceleration/deceleration. In an experimental chewing of gum bolus having standardized physical properties, adult subjects with functionally acceptable occlusion show reproducible pattern of chewing cycle with optimally simple jaw acceleration/deceleration whereas, the jaw acceleration/deceleration in prognathic patients with unstable occlusion is not (15). Comparisons of trajectories between the data and those predicted by the maximum-smoothness (minimum-jerk) model (11, 12) help explain the optimally smooth movement. Irregular characteristics of the jaw movement trajectories of patients with temporomandibular joint (TMJ) disorders have been identified in terms of large prediction error of the model simulation (16).

The derivative of movement acceleration (jerk) derives from the rate of change in resultant force that generates jaw movement. Jaw motion during functional tasks is shaped by dynamic changes in forces acting on the mandible including muscle tensions, TMJ reaction forces, and when teeth meet, occlusal reaction forces (17). Therefore, the jerk-cost (11, 12) of the motion reflects in the degree of variability of interaction between jaw muscle action and its reaction forces over time. The structures and biomechanical properties of occlusal/TMJ interfaces determine the magnitude and direction of the reaction forces (17). For patients with mandibular prognathism, it has been demonstrated that the jerk-cost of masticatory jaw movements is a valid indicator that differentiates between jaw-closing movements at pre- and post-orthodontic treatment (15).

This case report aimed to verify the necessity and effectiveness of the surgical-orthodontic treatment of a patient with mandibular prognathism by presenting remarkable post-operative improvements in the jaw movement smoothness during the gum-chewing task.

Case Report

Clinical examination

The patient was a 20 years and 10 months old male. His major complaint was difficulty in biting. The facial profile was concave (Fig. 1). Crossbite and cusp-to-cusp relationship were observed between maxillary and mandibular teeth in anterior to posterior regions (Fig. 1). The patient had no TMJ dysfunction or relevant medical history.

Cephalometric analysis of the patient revealed a skeletal class III relationship (ANB = −4.8°) with retroclined mandibular incisors (L1-FH = 79.0°). He had an overbite of 2.0 mm and an overjet of −5.0 mm.

Examination of jaw movement smoothness

The patient was asked to perform unilateral gum chewing with the posterior teeth on the habitually preferred side (left side), at a pitch he felt natural and comfortable. The physical properties of the gum were standardized (18) (width × length × depth: 15 × 20 × 1 mm; weight: 2 g; bloom strength: 80 g). Movement of the mandibular incisor-point during gum chewing was monitored by a kinesiograph (Kinesiograph Model K-5; Myotronics Inc., Seattle, WA, USA). The position of the magnetic transducer was zeroed at the origin when the maxillary and mandibular teeth were in complete intercuspation (CO position, Fig. 2). The data processing procedure is described in detail elsewhere (11, 19). In brief, mathematical function of the 20th order Fourier series was fit to each time series of lateral, antero-posterior, and vertical jaw displacement data for each chewing cycle. Thus, the functions $x(t)$, $y(t)$ and $z(t)$, which corresponded to the time series of each lateral, antero-posterior and vertical jaw displacement data, were obtained (11, 12). By differentiating the mathematical functions, tangential velocity [TV(t)] and tangential acceleration [TA(t)] were determined (Fig. 2). Movement smoothness was quantified using a time integral of squared jerk (jerk-cost, Fig. 2), where the jerk is defined as the rate of change in

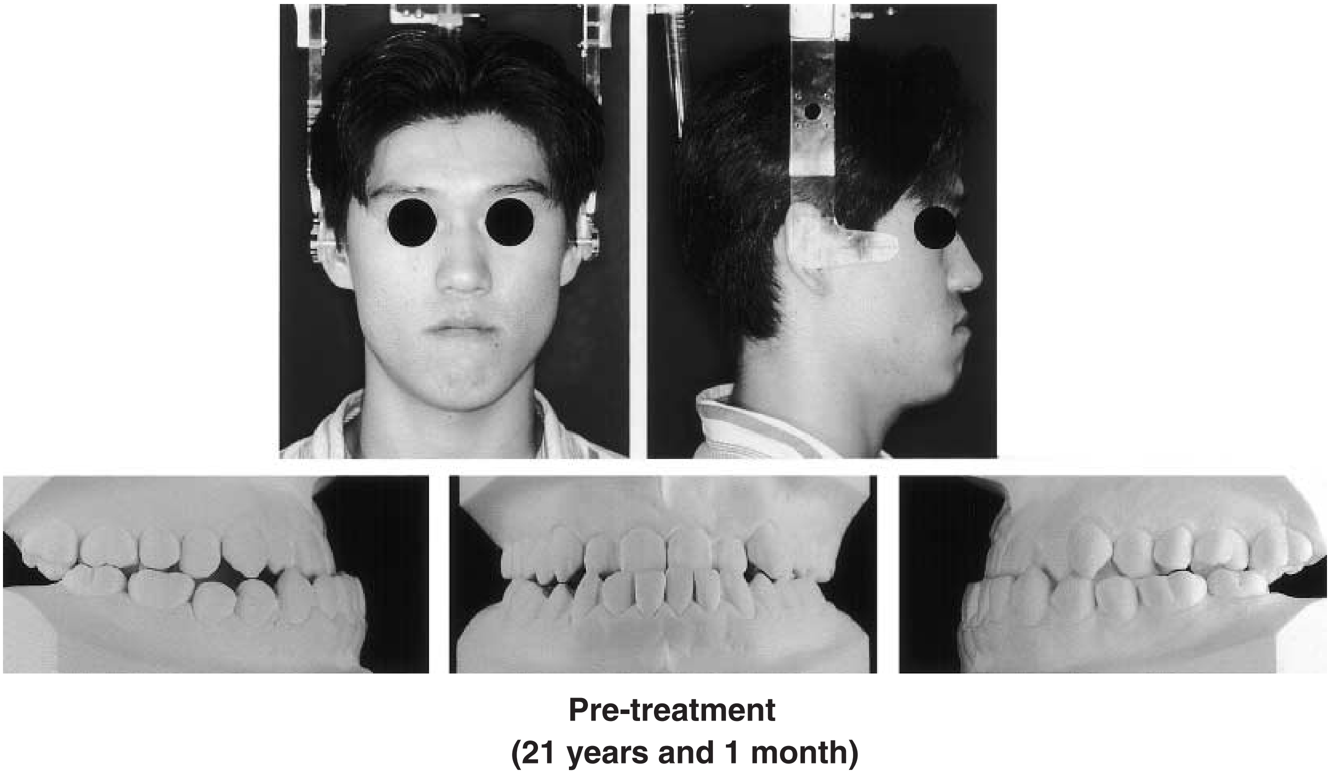

Fig. 1. Pre-treatment facial and intraoral photographs (21 years and 1 month).

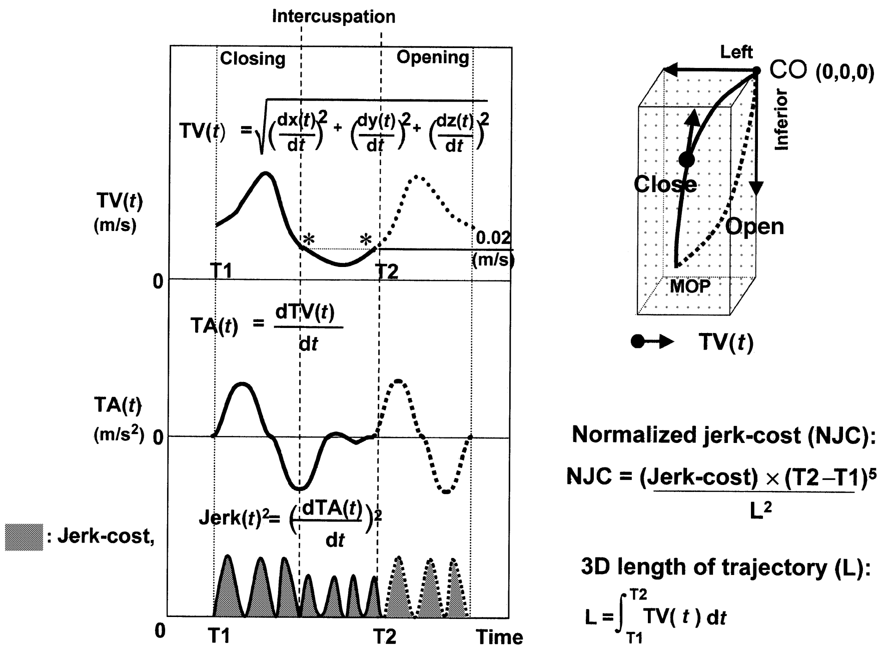

Fig. 2. Schematic representation of the kinematic parameters. The tangential direction represents the direction of the jaw movement vector in space. CO, centric occlusion position; TV(t), tangential velocity function; TA(t), tangential acceleration function; Jerk(t), jerk function; T1, beginning of jaw closing; T2, end of intercuspal phase. The shaded area denotes the jerk-cost in a chewing cycle. MOP, maximum opened position. The asterisks indicate beginning and end of the intercuspal phase. To allow comparison of the jerk-cost for a chewing cycle of varying duration and pathway length, the jerk-cost for each phase of a chewing cycle was expressed in normalized units of time and 3D pathway length by calculating the normalized jerk-costs, NJC[12].

acceleration (11). Decrease in the jerk-cost indicates an increase in movement smoothness. In addition, three-dimensional length of the trajectory was computed (Fig. 2).

The chewing data were visually checked on the computer monitor to reject deviant cycles caused by swallowing saliva. The chewing data of each cycle was divided into opening, closing, and intercuspal phases. The beginning and end of intercuspal phase were defined as the time periods when the tangential velocity crossed 0.02 m/s during closing and opening, respectively (Fig. 2).

The kinematic features of jaw movements during closing and intercuspal phases at the pre- and post-treatment stages were compared. The post-treatment jaw movement was recorded 2 years and 8 months after completion of the retention period (5 years after surgery). To allow comparison of the jerk-cost for the movement of varying duration and pathway length, the jerk-cost during closing and intercuspal phases for each chewing cycle was expressed in normalized units of time and 3D pathway length by calculating the normalized jerk-costs, NJC (12) (Fig. 2). The NJC, phase duration, peak tangential velocities, and the mean tangential velocity profiles were also calculated.

The recently developed minimum-jerk (maximum-smoothness) model (12) simulated the velocity profile of each individual jaw movement in closing phase. Deviation of the velocity profiles between the model based and actual movements was measured by using $1\text{-}R^2$ [termed as an unexplained variance, UV (%), where R is a correlation coefficient between the model based and actual velocity profiles] (20). The UVs of the simulation were compared between the two stages.

Treatment plan

1 Extraction of mandibular third molars.
2 Alignment of all teeth by a pre-adjusted edgewise appliance.
3 Bilateral mandibular setback by sagittal split ramus osteotomy (SSRO).
4 Retention.

Treatment progress

Pre-adjusted edgewise appliance treatment was initiated at the age of 21 years and 1 month. The mandible was setback bilaterally (7 mm) by SSRO when the patient was 23 years and 9 months old. The edgewise treatment was completed at the age of 24 years and 2 months. The patient was instructed to wear Hawley type retainers for the next 2 years.

Results

All crossbite relationships between maxillary and mandibular teeth were corrected. An ideal class I dental occlusion was obtained, with favorable overbite (2.0 mm) and overjet (2.5 mm) (Fig. 3). Figure 4 shows a superimposition of pre- and post-treatment cephalometric tracings. The ANB angle increased to −2.7°. Two years and 8 months after the retention period (5 years after surgery), the occlusion remained stable with improved facial esthetics.

Figure 5 compares the mean jaw-closing movement trajectories while chewing with the left side. After treatment, the patient demonstrated wider lateral excursions during jaw closing than in the pre-treatment stage.

Figure 6 shows the horizontal view of the jaw-closing movement trajectories during intercuspal phase. The pathway length of the mandibular incisor point was greater in the post-treatment stage, compared with the pre-treatment stage ($p < 0.05$, Wilcoxon signed rank test).

Figure 7 compares the NJC during the jaw-closing. The NJC of the patient were also compared with the reported normative value, which is the median of NJC for 20 subjects who exhibited acceptable occlusion (15). After the retention period, the NJC was significantly reduced to a level comparable with that of subjects with good occlusion ($p < 0.05$, Wilcoxon signed rank test).

Figure 8 shows comparisons of mean temporal changes for tangential velocity together with the results obtained by the minimum-jerk model prediction. The peak velocity at the post-retention period was significantly greater than that at the pre-treatment stage. The duration of jaw-closing phase at the post-retention period was significantly shorter than that at the pre-treatment stage (all $p < 0.05$, Wilcoxon signed rank test). In contrast, the duration of intercuspal phase at the post-retention period was significantly longer than that at the pre-treatment stage (all $p < 0.05$, Wilcoxon signed rank test). The simulation error for the velocity profile recorded at the post-treatment stage became negligible as compared with that at the pre-treatment stage ($p < 0.05$, Wilcoxon signed rank test; median of the unexpected variance (UV), 30.6% for the pre-treatment; 2.3% for the post-treatment).

Discussion

The masticatory function improves with achievement of a dynamic inter-occlusal condition that allows efficient food-breakage. The variation in chewing

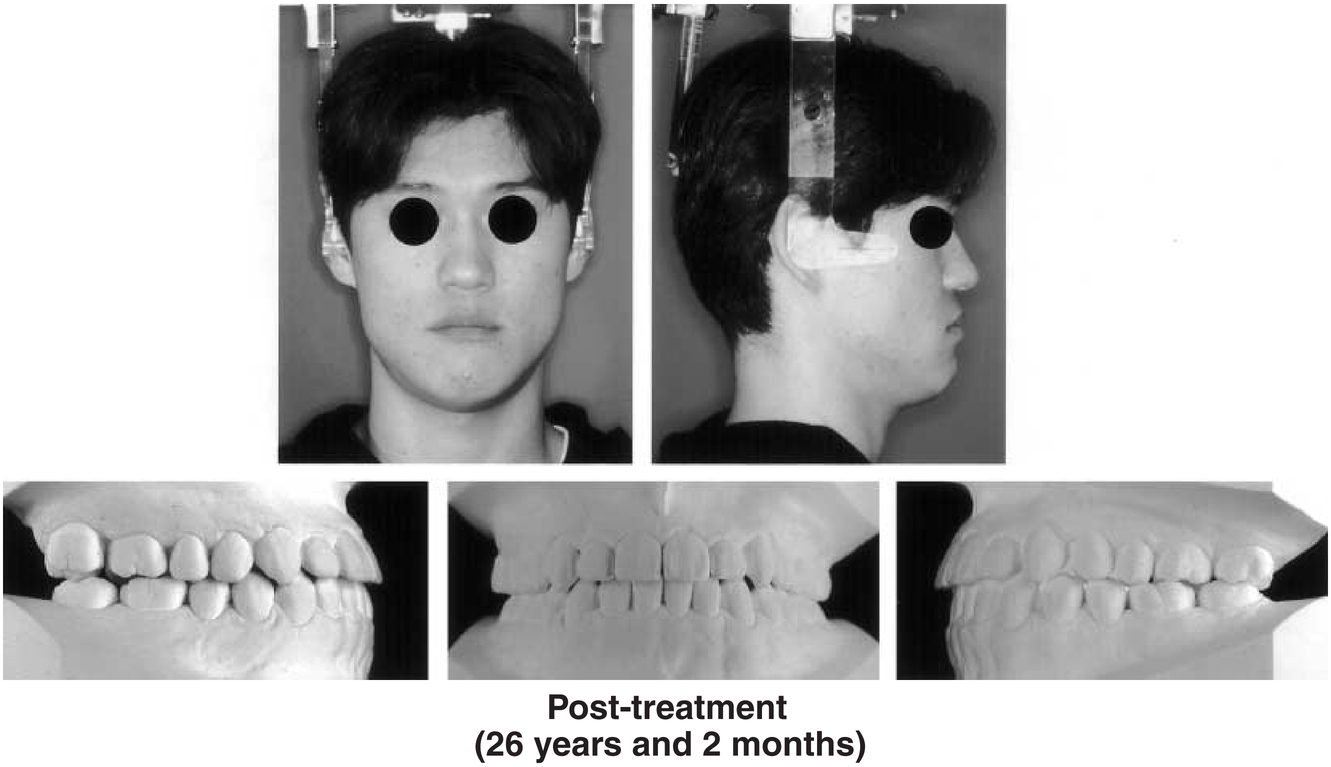

Fig. 3. Post-treatment facial and intraoral photographs at (26 years and 2 months).

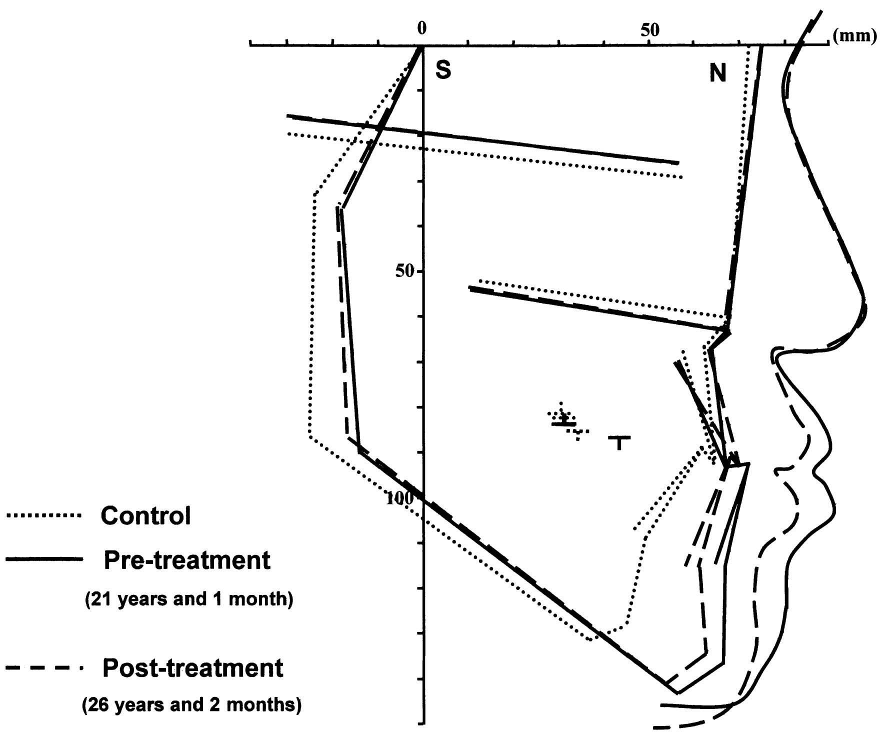

Fig. 4. Superimposed tracings of lateral cephalograms on cranial base. S, Sella; N, Nasion.

performance in terms of food size reduction has been explained by differences in types of occlusal condition (6), area of occlusal contact (5, 6) and efficacy of specific mandibular movement parameters (1–4). Several studies (1–4) suggest that differences in the jaw movement might have a greater influence on chewing performance than static occlusal contact area, i.e. kinematic parameters such as tremor of the jaw

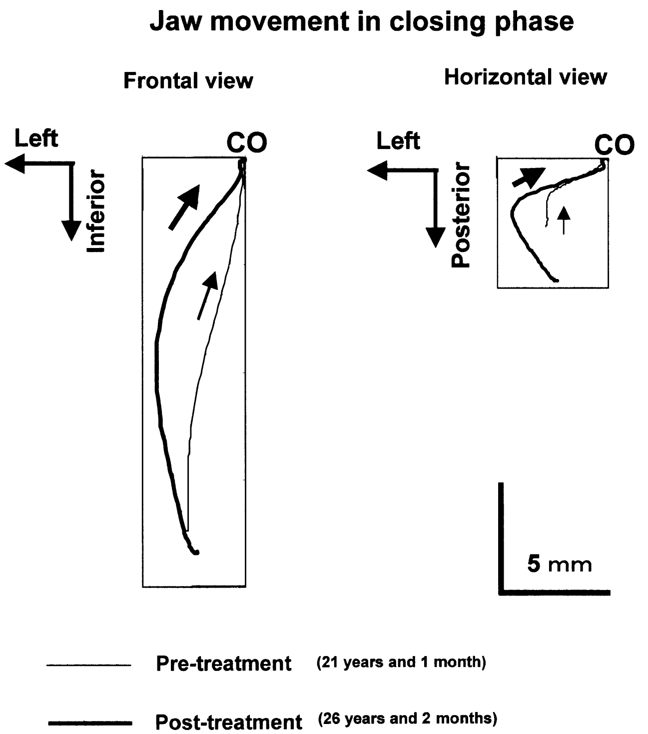

Fig. 5. Comparison of mean jaw-closing movement pattern during chewing on the left side in pre-treatment (21 years and 1 month) and post-treatment (26 years and 2 months) stages. Thin lines, pre-treatment (n = 23 cycles); thick lines, post-treatment (n = 25 cycles). Arrows indicate direction of movement. CO, centric occlusion position.

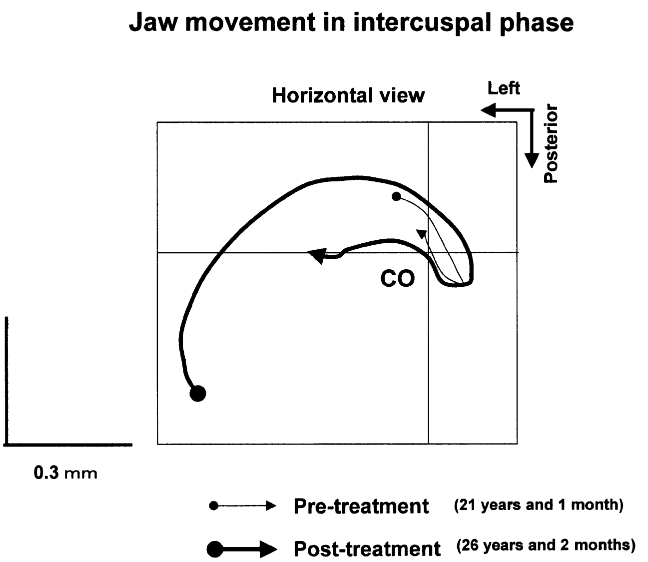

Fig. 6. Comparisons of jaw-closing movement trajectories in the intercuspal phase during chewing on the right side. Thin line, mean of the 23 trajectories in pre-treatment stage (21 years and 1 month); thick line, mean of the 25 trajectories in post-treatment stage (26 years and 2 months). Arrows indicate direction of movement. CO, centric occlusion position.

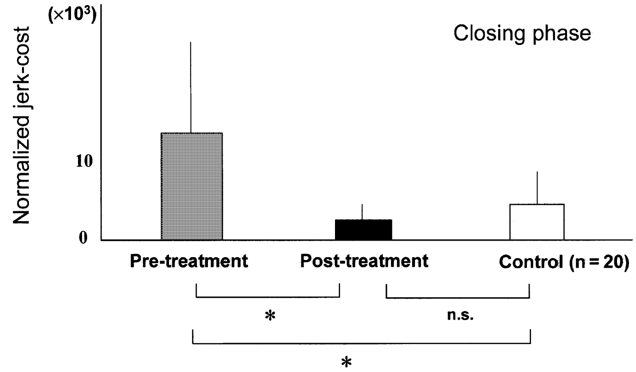

Fig. 7. The normalized jerk-cost for the jaw-closing movement during chewing on the left side in pre- and post-treatment stages. The bars and thin lines denote median and range (23 and 25 cycles for the pre- and post-treatment stages, respectively). For comparison, control value of jaw movements in 20 adult subjects with good occlusions was cited from a recent report (15). The normalized jerk-cost is a dimensionless value (see Figure 2). Asterisk denotes a significant difference.

movement are able to predict the chewing performance (2). Recently, it has been reported that subjects with Class III malocclusion show limited chewing performance, because of smaller areas of near occlusal contact, compared with those with class I and II malocclusion (6). Based on these findings, it seems reasonable to speculate that masticatory efficiency is associated with direction and magnitude of occlusal force vector during jaw-closing, which is dependent on movement deceleration and tooth contact areas near intercuspation [0.2–0.45 mm inter-occlusal distance (1, 6)].

In the present case, the jaw motion, which was slower than 0.02 m/s (intercuspal jaw movement during contact and near contact condition), was within the range of 0.5 mm inter-occlusal distance. The longer pathway and duration of the intercuspal phase observed in the post-treatment stage (Fig. 6) indicates that the correction of crossbite allowed the patient to use larger area of occlusal platforms. Because the jaw-postural stability was not provided by the dentition in the present case, we infer that the jaw muscles contributed to stabilization of the mandibular position during intercuspation so as to avoid damage to the teeth at the pre-treatment stage. After treatment, we suggest that the dentition plays a major role in stabilizing the mandibular position and the elevator muscles may be able to exert more isometric force during intercuspation. Correction of the crossbite also allowed the mandible to close with wider lateral excursion. While generating stronger occlusal force during mastication, laterally excursed jaw-closing

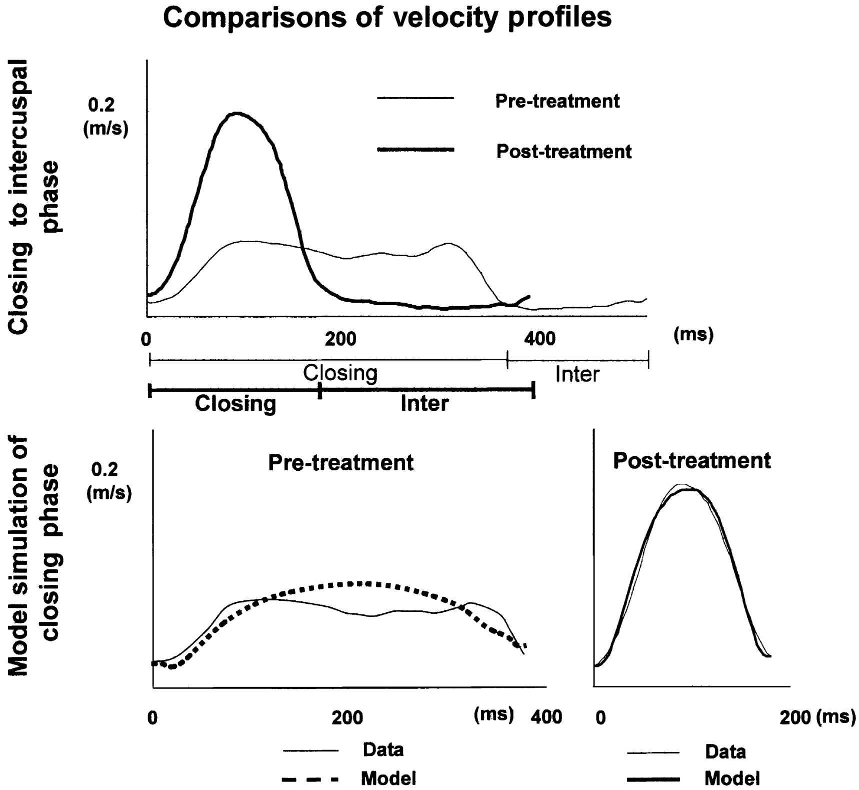

Fig. 8. Mean tangential velocity profiles and those predicted by the minimum-jerk models. Upper column, comparison of the velocity profiles in closing to intercuspal phase between the two stages; Lower column, comparisons of velocity profiles in closing phase between the data and model-prediction; pre-treatment, mean of 23 jaw-closing movements during chewing on the left side; post-treatment, mean of 25 chewing cycles during chewing on the left side. Inter, intercuspal phases; closing, closing phase.

movement is enhanced in both animals (21–23) and humans (7–9, 19). In addition, chewing efficiency relates to a widely excursed jaw-closing movement (1). Accordingly, the wider lateral excursion during closing observed in the post-treatment stage suggests the capability of the patient to generate more effective occlusal force.

The simulation outcome by the minimum-jerk (maximum smoothness) model provides explanation of the optimal smoothness, i.e. the model predicts the smoothest possible velocity profile in the actual boundary conditions (12) (e.g. measured duration, velocity at the start and end of the movement) for a chewing cycle. At the pre-treatment stage, greater normalized jerk-cost of the jaw-closing movement was associated with greater prediction error for the velocity profile. This derived from the rapid and irregular change in velocity and absence of an apparent peak of the velocity during the closing motion (Fig. 8). After treatment, however, the normalized jerk-cost decreased and the temporal changes in acceleration/deceleration of the actual motion became well patterned and much closer to those predicted by the model. Based on the observations that a significantly negative relationship exists between the jaw movement smoothness and unstable occlusal conditions (15), and improvement of the jaw movement smoothness occurs after orthodontic treatment (15), we suggest that the achievement of wider inter-occlusal contact area after the treatment allowed the patient to avoid irregular deceleration of the jaw-closing.

The patient showed a significantly higher peak of tangential velocity and shorter duration of the jaw-closing phase after treatment (Fig. 8). It has been demonstrated that the duration of elevator muscle activity during chewing is inversely proportional to the stability of functional occlusion (24). It should be reasonable to assume that slower jaw-closing movement in the pre-treatment stage is associated with prolonged duration of jaw-elevator muscle activity, which contributes to stabilization of the mandibular position near the CO position.

Based on the present and previous findings, it can be concluded that in this case the occlusal adjustment resulted in the remarkable optimization or simplification of the jaw closing movement during experimental gum chewing. The well-patterned motion indicates an achievement of certain economy in movement execution. The present findings of favorable changes in jaw movement kinematics justify the necessity of the surgical-orthodontic treatment of mandibular prognathism to improve jaw motor function.

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