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Effect of Wearing a Maxillofacial Prosthesis on Masticatory Rhythm Improvement in Mandibulectomy Patients

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Abstract

Background: Recording jaw movement rhythms in patients with jaw defects is challenging using conventional tracking devices. However, masticatory rhythm is crucial for masticatory performance and nutritional intake. This study aimed to explore the impact of using a maxillofacial prosthesis to restore masticatory rhythm in mandibulectomy patients with a novel wearable device. **Methods:** Twelve patients who underwent mandibulectomy and were rehabilitated with maxillofacial prosthesis were recruited. Chewing rate, cycle durations, coefficient of variation of cycle durations (CV), changing times of skin morphology on the back of the ear pinna area (SM), and masticatory performance were measured during gum chewing without and with a denture using a wearable jaw movement rhythm tracking device. A paired t-test and the Pearson correlation coefficient were used for statistical analysis. **Results:** The chewing rate increased by 8.6 cycles/min with dentures ($P < 0.001$). Cycle durations with dentures were reduced by 0.13 s/cycle ($P = 0.01$). The CV and SM decreased with dentures ($P = 0.004$ and $P = 0.01$, respectively). Significant correlations were found between the CV and SM without dentures ($P = 0.004$). **Conclusion:** 1. Wearing maxillofacial prostheses can improve masticatory rhythm in patients who undergo mandibulectomy with Eichner B2 occlusal supports. 2. The wearable device is available for measuring masticatory rhythm in patients with jaw defects in clinics. 3. Changing times of the skin morphology on the back of the ear pinna indicate jaw movement stability through a simpler process than the coefficient of variation of cycle durations.

Keywords

Masticatory Rhythm, Jaw Movement Rhythm Tracking Device, Maxillofacial Prosthesis, Head and Neck Tumor, Mandibulectomy

1. Introduction

Malnutrition and impaired masticatory performance are common in patients with head and neck tumors [1]. Those with jaw defects from tumor resection often experience a loss of skeletal muscle mass and incomplete dentition, leading to longer chewing times or swallowing larger food particles [2], which strains their ingestion and nutrient availability [3] [4]. The use of mounted jaw movement tracking devices and various accessories has made clinical jaw measurement complex [5]-[11]. This is particularly challenging for patients with significant jaw defects, as prosthodontists struggle to monitor masticatory rhythm and make necessary adjustments.

Rhythmic mastication is a key characteristic of healthy chewing, maintained by a central pattern generator (CPG). The CPG receives input from mechanoreceptors in the periodontal ligament and masticatory muscles, coordinating the tongue, facial, and jaw muscles to transport food bolus for swallowing [12] [13] [14]. Masticatory rhythm can be measured as chewing rate (cycles/min), a behavior parameter, or cycle duration (seconds/cycle), a temporal jaw movement parameter, along with the stability of jaw movement [14] [15]. Normal masticatory cycle values range from 70 - 90 cycles/min, with interindividual variations being wider than intraindividual variations [14]-[16]. It is well documented that a lower frequency aids in detecting smaller and foreign objects in food but reduces energy and meal intake. In contrast, a higher and stable frequency leads to better masticatory performance and a lower risk of metabolic syndrome [3] [4] [14] [16]-[19]. Meal intake is the primary method of nutritional intake and is essential for patients undergoing treatment for head and neck tumors. The literature indicates a positive correlation between chewing rate and meal size [19]. Previous studies have indicated that masticatory rhythm improves with the insertion of various types of prostheses, such as complete dentures, removable partial dentures, single molar crowns, implant-supported overdentures, or implant-supported fixed partial dentures for missing teeth, using mounted and intrusive devices in experimental laboratories. Additionally, some research suggests that individuals with inadequate dentition may chew faster to compensate for their compromised masticatory performance [2] [5]-[11] [20] [21]. The discrepancy remains unclear. Furthermore, the effects of maxillofacial prosthesis insertion on masticatory rhythm (chewing rate, cycle duration, and stability of jaw movement), as well as the impact of adjuvant therapy and flap reconstruction, have not been clarified.

Recently, a new ear-hanging wearable device, the bitescan BH-BS1RR (Sharp

Co., Sakai, Japan), being correctly placed on the right ear, measured daily chewing frequency with accuracy, precision, and recall [3] [4] [22]. This study used it to record jaw movements in a clinic for patients who underwent mandibulectomy.

This study aimed to explore the impact of using a maxillofacial prosthesis on restoring masticatory rhythm in mandibulectomy patients with Eichner B2 occlusal supports. It also examined the feasibility of employing a novel wearable device for detailed tracking of jaw movements in a clinical setting. Furthermore, the study sought to identify a method for measuring masticatory rhythm that simplifies the process and reduces the time required, benefiting patients and prosthodontists during clinical treatment. The null hypothesis was that maxillofacial prosthetic treatment would not improve masticatory rhythm in mandibulectomy patients with Eichner B2 occlusal supports.

2. Materials and Methods

2.1. Study Population

Twelve patients who had undergone mandibulectomy with Eichner B2 occlusal supports (6 men and 6 women, mean age 59.5 years; age range 41 - 78 years, including 3 marginal and 9 segmental) participated in this study (**Table 1**). All patients were rehabilitated with a mandibular removable partial denture at the Clinic for Maxillofacial Prosthetics of Tokyo Medical and Dental University Hospital (**Figure 1**).

The statistical power was calculated using Power Analysis and Sample Size (PASS 2021, v21.0.3, NCSS, LLC, Kaysville, UT, USA). It was found to be 1, based on a sample size of 12, the null hypothesis that the mean of paired differences is zero, the observed mean of paired differences, and the standard deviation of these differences [23]. These calculations were conducted with a specified random seed to ensure reproducibility, utilizing 2,000 simulations for accurate estimation of the power [23].

This study was approved by the Ethics Committee of Tokyo Medical and Dental University (Approval No. D2021-084), and informed consent was obtained from all patients prior to enrollment. The inclusion criteria included patients undergoing marginal or segmental mandibulectomy with Eichner Classification B2 (at least 2 occlusal contacts in the molar region), representing characteristics of most patients with incomplete dentition [24]. Participants had complete maxillary dentition and had worn a well-fitted mandibular denture for at least 3 months after insertion (**Figure 1**). Patients with glossectomy, severe periodontal disease, temporomandibular disorders, mucosal trauma, trismus, or central nervous system diseases were excluded to minimize any potential damage, except for those undergoing mandibulectomy. Age, sex, time since surgery, benign or malignant conditions, neck dissection, radiotherapy, the number of remaining teeth, contact teeth, mandibular canines, Eichner classification, type of mandibulectomy, and reconstruction were determined from medical histories and intraoral examinations (**Table 1**).

Table 1. Patients' characteristics.

Patients No.	Age	Sex	Time since surgery	Benign or Malignant	Neck dissection	Radiotherapy	No. of remaining teeth	No. of contact teeth	No. of mandibular canines	Eichner classification	Mandibulectomy	Reconstruction
A	52	Woman	1y9m	Benign	(-)	(-)	20	6	1	B2	Segmental	Metal plate
B	59	Woman	29y	Benign	(-)	(-)	20	4	0	B2	Segmental	Ilium
C	41	Woman	6y	Benign	(-)	(-)	20	6	1	B2	Segmental	Fibula osteocutaneous free flap
D	48	Woman	4y10m	Benign	(-)	(-)	21	9	2	B2	Segmental	Scapula
E	54	Woman	4y11m	Malignant	Left	(-)	26	10	1	B2	Segmental	Scapula osteocutaneous free flap
F	65	Man	3y	Malignant	Bilateral	(-)	17	5	1	B2	Segmental	Metal plate + PMMC flap
G	78	Man	13y11m	Malignant	Right	30Gy	22	8	1	B2	Segmental	Scapula osteocutaneous free flap
H	65	Man	5y8m	Malignant	Left	(-)	21	7	1	B2	Segmental	Scapula osteocutaneous free flap
I	74	Woman	5y10m	Malignant	Left	(-)	23	8	1	B2	Marginal	Forearm flap + Reinforcement plate
J	53	Man	11y3m	Malignant	Left	(-)	27	11	2	B2	Segmental	Fibula osteocutaneous free flap
K	60	Man	10y2m	Malignant	Left	(-)	23	9	2	B2	Marginal	Forearm flap + Reinforcement plate
L	65	Man	1y3m	Malignant	(-)	(-)	24	10	2	B2	Marginal	No

PMMC: pedicled pectoralis major myocutaneous.

(A) (B)

Figure 1. Intraoral views of segmental mandibulectomy patient. (A) Without denture; (B) With denture.

2.2. Masticatory Rhythm Examinations

The masticatory rhythm was measured by having participants chew gum 100 times, both without and with dentures, using the bitescan (bitescan BH-BS1RR, Sharp Co.). This innovative wearable device is equipped with an infrared distance sensor and an accelerometer, operating at a 20 Hz mastication frequency. It scans the morphological changes in the skin surface on the posterior side of the pinna. The data were recorded on a smartphone application (SHM05, Sharp

Co., Sakai, Japan) connected to the device via Bluetooth (**Figure 2(A)**). The bitescan features an adjustable ear-hook designed to be worn on the right side (**Figure 2(B)**). It comes in three sizes (S, M, and L) to ensure a perfect fit for each participant's pinna [22]. The bitescan of a wearable device is lightweight and wireless, making it easy to mount and enabling measurement anywhere without the need for specific devices. This overcomes the challenge of evaluating masticatory movement outside the clinic or laboratory. It can also monitor chewing frequency in everyday life without disturbing mandibular or cervical movements [22].

Each patient was instructed to sit, relax, and calibrate jaw movements with a mandibular denture. The calibration process, which included jaw opening, closing, and lateral chewing movements, was demonstrated step by step on the bitescan application by the clinician to mitigate the effects of irregular jaw movements such as deviation, rotation, and lateral chewing on masticatory rhythm. A color-changeable chewing gum (Masticatory Performance Evaluating Gum XYLITOL, Lotte Co., Ltd., Tokyo, Japan) served as the test food. Patients practiced chewing freely for 30 seconds before the evaluation, then performed freestyle mastication for 100 cycles without and with dentures, separated by a 3-minute interval to prevent muscular fatigue [25] [26].

The masticatory rhythm was measured through chewing rate (cycles/min), cycle durations (s/cycle), the coefficient of variation of cycle durations (CV = standard deviation/mean), and the number of changing times in the skin morphology on the back of the ear pinna (SM). In this study, CV and SM were indicators of jaw movement stability. A larger deviation from the mean value (higher CV and SM) indicated lower stability in jaw movement. The chewing rate for the entire 100 bites was derived from the bitescan algorithm. Cycle durations, CV, and SM were recorded from 10 cycles starting 20 seconds after the gum became a soft bolus (**Figure 3**) [27].

2.3. Masticatory Performance Examinations

Masticatory performance and rhythm were measured simultaneously. Immediately after chewing, the gum was collected, compressed to a thickness of 1.5 mm

(A) (B)

Figure 2. Bitescan system. (A) Bitescan is connected to a smartphone via Bluetooth; (B) Bitescan in position.

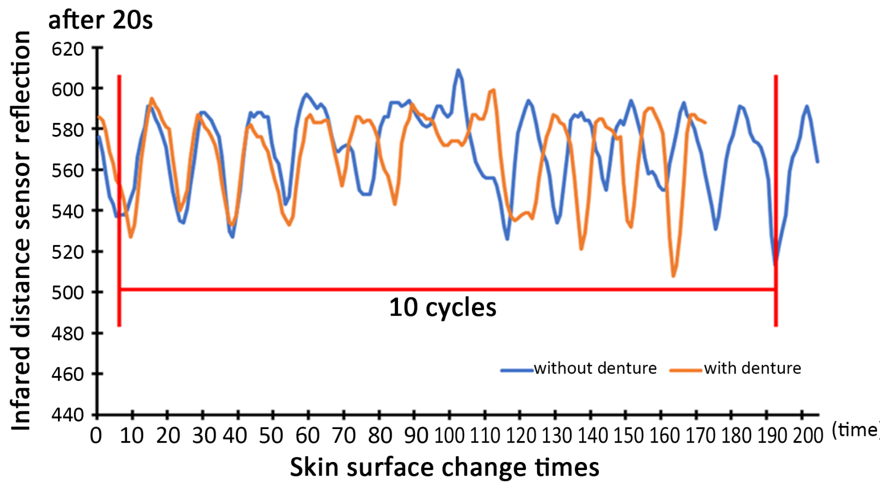

Figure 3. Changes in skin morphology on the back of the ear pinna after 10 cycles.

in polyethylene films between two glass plates, and then the upper glass plate was removed. Its color was measured through the polyethylene film using a colorimeter (CR-13, Konica Minolta, Inc., Tokyo, Japan). The color of the compressed gum was assessed at five points, and an average value was calculated. Color assessment was conducted using the CIE-Lab* color space. The food mixing ability (ΔE) was measured as an indicator, with a higher score indicating greater mixing ability [25].

2.4. Satisfaction for Dentures

Patients' satisfaction with eating, chewing, and overall denture quality was measured using a visual analog scale (VAS) scored from 0 to 100, representing perceived denture satisfaction [28].

2.5. Statistical Analysis

The mean masticatory rhythm (chewing rates, cycle durations, CV, and SM) and masticatory performance data were normally distributed according to the Shapiro-Wilk test. Therefore, a paired t-test was used for statistical analyses to compare masticatory rhythm and performance without and with dentures. P-values < 0.05 were considered statistically significant. Correlations between the CV and SM were analyzed using the Pearson correlation coefficient, with a significance level of P < 0.01. All analyses were performed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, NY, USA).

3. Results

Table 1 presents patient characteristics, including a mean age of 59.5 years (range 41 – 78 years), an equal gender distribution with 6 men and 6 women, a post-surgery duration ranging from 1 year 3 months to 29 years, and a diagnosis breakdown of 4 benign and 8 malignant cases. Further details include 7 patients undergoing neck dissection, 1 receiving radiotherapy, a range of 17 – 27 remaining teeth and 4 - 11 contact teeth per patient, 0 - 2 mandibular canines, Eichner B2 occlusal supports, types of mandibulectomy (3 marginal and 9 segmental), and reconstruction methods (2 metal plate and 7 bone reconstructions). Mandibular continuity was maintained in all patients.

Table 2 and Figure 4 present the results for masticatory rhythm and performance. The masticatory frequency increased significantly by 8.6 cycles/min with dentures compared to without dentures (P < 0.001). Cycle durations decreased significantly by 0.13 s/cycle with dentures compared to without dentures (P = 0.01). The coefficient of variation of cycle durations (CV) in jaw movement stability significantly decreased with dentures compared to without dentures (P = 0.004), and the number of changing times in the skin morphology on the back of the ear pinna (SM) significantly decreased with dentures compared to without dentures (P = 0.01). No significant difference was observed in masticatory performance between the two groups (P = 0.72).

Figure 5 displays the values of the CV and SM, revealing significant correlations between the CV and SM in individuals without dentures ($P = 0.004$).

According to VAS, patients' mean satisfaction scores for eating, chewing, and dentures were 81.7 ± 10.1, 80.0 ± 11.9, and 85.8 ± 8.2, respectively.

Table 2. Results of masticatory rhythm and masticatory performance.

	Chewing rate (cycles/min)	Cycle duration (seconds/cycle)	CV	SM	Masticatory performance (ΔE)
Without denture (n = 12)	80.7 ± 10.1	0.72 ± 0.16	0.48 ± 0.18	153.0 ± 32.1	53.8 ± 3.2
With denture (n = 12)	89.3 ± 10.3	0.59 ± 0.10	0.30 ± 0.16	126.0 ± 19.3	53.5 ± 2.2
P	< 0.001*	0.01*	0.004*	0.01*	0.72

CV: coefficient of variation from cycle durations; SM: changing times of skin morphology on the posterior of ear pinna. Paired t-test: *$P < 0.05$.

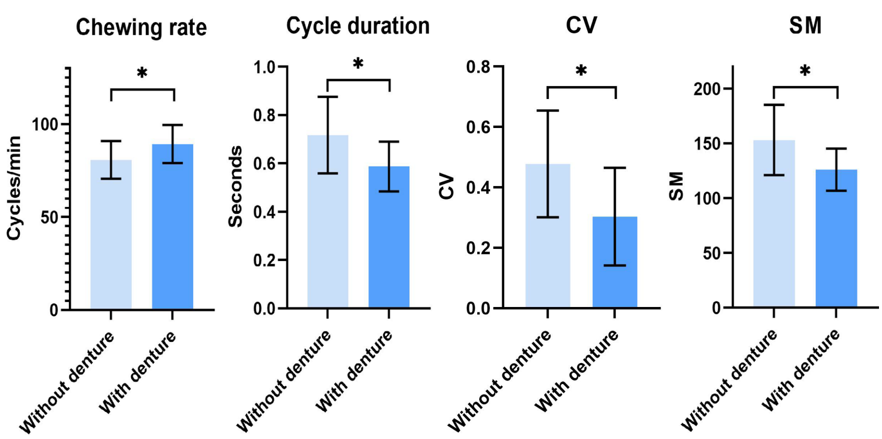

Figure 4. Results of chewing rate, cycle duration, coefficient of variation from cycle durations (CV), and changing times of skin morphology on the posterior of the ear pinna (SM). Paired t-test: *$P < 0.05$.

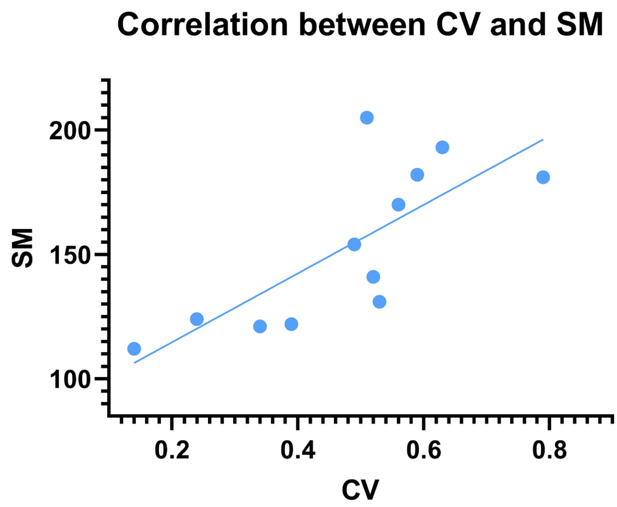

Figure 5. The correlation between CV and SM without dentures. CV: coefficient of variation from cycle durations; SM: changing times of skin morphology on the posterior of the ear pinna. R2 = 0.577, $P = 0.004^{**}$.

4. Discussion

In the current study, patients' mean satisfaction with eating, chewing, and overall denture quality was high (over 80 points on the VAS), indicating no problems with the quality of the dentures [11] [28]. Patients reported ease in eating after denture insertion. The chewing rate for those wearing mandibular dentures increased by an average of 8.6 cycles/min (10%), with a range from 1 to 22 cycles/min, and the coefficient of variation of cycle durations (CV) with dentures decreased by an average of 0.18. This indicates that masticatory rhythm (chewing rate and CV) can be significantly improved and stabilized with maxillofacial prosthetic treatment for mandibulectomy patients with Eichner B2 occlusal supports, even in a small sample size. Therefore, the null hypothesis was rejected.

The results aligned with studies showing an increase in masticatory cycles following the insertion of removable partial dentures, new complete dentures, single molar crowns, implant-supported overdentures, or implant-supported fixed partial dentures using conventional jaw tracking devices [5]-[10]. The changes in masticatory behavior could be due to the restoration of altered oral anatomy and sensorimotor coordination by the reestablished dental arch and occlusal contacts. The stabilization of occlusion provided by the mandibular dentures resulted in significant muscular control, improved balance, and harmony of mandibular movement during chewing [14]. However, the varied improvements in masticatory cycles might be related to different levels of denture adaptation, types of retention, occlusal surface morphology, and occlusal contact area, even though these are not directly comparable due to the lack of standardized methods.

Regarding the stability of jaw movement (CV), a large variation from the mean values of cycle durations indicates poor masticatory function due to impaired orofacial components and occlusal factors. Conversely, a reduced CV suggests better masticatory function [6] [14] [29]. However, limited variability might also indicate the stomatognathic system's failure to adapt to the task or a higher risk of wear on anatomical structures [14].

Previous studies used the coefficient of variation of cycle durations (CV) to represent the stability of jaw movement [6]. This study aimed to use the number of changing times in the skin morphology on the back of the ear pinna (SM) from cycles obtained via the infrared distance sensor of the bitescan as a measure of stability, and the trends in SM were consistent (**Figure 5**). A decrease in SM indicated more stable jaw movement. These findings suggest that SM could represent jaw movement stability through a simpler process than CV. However, further research is needed to understand the reliability of SM as an indicator of jaw movement stability across individuals with different oral health conditions.

Patients A and F underwent segmental mandibulectomy with metal plate reconstruction. Patient A received a denture supported by primary closed mucosa, while Patient F was fitted with a denture supported by a flap. Notably, Patient F exhibited a higher coefficient of variation of cycle durations (CV) in masticatory rhythm with the denture compared to before its insertion, indicating a deterioration in jaw movement stability. Conversely, Patient A demonstrated a stable masticatory rhythm after receiving the denture, suggesting that denture provision might not effectively rehabilitate masticatory rhythm in cases of flap reconstruction with mobility.

The masticatory performance showed no significant differences between groups without and with dentures, which contradicted the observed masticatory rhythm. Despite this, patients reported an ease in eating after denture insertion. Masticatory performance in this study was evaluated by chewing gum 100 times, rather than by duration (e.g., 1 or 2 minutes). Improvements in masticatory rhythm, through acceleration and stabilization, might reveal differences in masticatory performance between the groups if assessed over a longer chewing duration. Additionally, specific factors related to masticatory function in patients with maxillofacial defects include residual teeth, defect configuration and size, prosthesis stability, maximum mouth opening, and occlusal force [30]. Further studies are needed to establish correlations between masticatory rhythm and performance, incorporating larger variations.

This study had several limitations. The data for the control groups or before surgery was not established due to ethical issues; thus, it was not possible to determine how maxillofacial prostheses preserve masticatory rhythm using the same methodology. Additionally, due to the narrow and strict inclusion criteria, larger sample sizes with higher statistical power are necessary to further investigate the correlation between masticatory rhythm and performance, as well as nutritional status in patients with head and neck tumors.

The main drawbacks of traditional jaw tracking devices were their cost and the complexity of mounting them, making them less accessible for prosthodontists and patients in clinical settings. The bitescan is an innovative, wearable device for tracking jaw movement rhythms that captures detailed jaw movements with minimal intrusion and is easy to recall, reducing the treatment burden and the need for complex accessories for both prosthodontists and patients. A maxillofacial prosthesis can enhance and stabilize the masticatory rhythm, offering additional insights for maxillofacial prosthesis rehabilitation by considering chewing habits, temporal jaw movements, masticatory performance, and nutritional availability for patients treated for head and neck tumors.

5. Conclusions

Based on the findings of this clinical study, the following conclusions were drawn:

1. Wearing a maxillofacial prosthesis can accelerate and stabilize the masticatory rhythm in patients undergoing marginal and segmental mandibulectomy with Eichner B2 occlusal supports.
2. The bitescan is available for measuring masticatory rhythm in patients with jaw defects at the chairside in clinics.
3. Changing times of the skin morphology on the back of the ear pinna (SM) can indicate the stability of jaw movement in a simpler way compared to the coefficient of variation of cycle durations (CV).

Ethical Statements

This study protocol was designed in accordance with the ethical principles of the Declaration of Helsinki and approved by the Ethics Committee of Tokyo Medical and Dental University (Approval No. D2021-084). Written consent was obtained from all patients before beginning assessments.

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Author Contributions

Xuewei Han: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing—original draft, Writing—review & editing. Mihoko Haraguchi: Formal analysis, Investigation, Methodology. Yuka I. Sumita: Project administration, Resources, Supervision. Marwa Ahmed Aboelez: Writing—review & editing. Noriyuki Wakabayashi: Supervision, Writing—review & editing.

Data Availability Statement

Data cannot be shared publicly because the data is owned and saved by Tokyo

Medical and Dental University. Data are available from the Ethics Committee of Tokyo Medical and Dental University for researchers who meet the criteria for access to confidential data: contact address, pararotti.mfp@tmd.ac.jp.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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