Identification of malocclusion risk factors after closed treatment of condylar fractures using a novel three-dimensional computed tomography approach

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Abstract: The condyle is the most common site of mandibular fracture. In the present study, a method was made to utilize three-dimensional computed tomography (3D-CT) images to evaluate mandibular condylar fractures and identify prognostic indicators of malocclusion after closed treatment. Accurate morphometric measurements were performed using 3D-CT images obtained before trauma, after trauma, and post-healing. Morphometry revealed significant differences in loss of ramus height (LRH) and lateral movement length in patients with malocclusion, and significant LRH differences in patients with other maxillomandibular fractures after healing, or in those with dislocation-displacement. The present method of 3D-CT image analysis appears useful for evaluation of condylar fractures.

Keywords: classification, condylar fracture, lateral movement length, post-traumatic malocclusion [1-3].

Identification of prognostic factors
Malocclusion was examined statistically in relation to sidedness, the presence of other maxillomandibular fractures, and the MacLennan classification [4].

Materials and Methods
Study subjects
The study design was approved by the Institutional Review Board of Tokyo Metropolitan Hiroo Hospital (expedited review approval No. 2018-29). A total of 104 patients treated for condylar fractures at the Tokyo Metropolitan Hiroo Hospital from April 2008 to March 2018 were investigated. Of these patients, 79 underwent closed treatment (106 sides) (excluding the patients younger than 16 years of age). Occlusion was evaluated in 74 patients for whom occlusal data had been obtained from their medical records for at least 3 months after treatment, and the following studies were performed.

Introduction
The condyle is the most common site of mandibular fracture [1,2]. Condylar fractures can be repaired by either open reduction and internal fixation (ORIF) or closed treatment. Closed treatment can be performed without postoperative complications after ORIF; however, in cases where there is significant bone fragment displacement, deformed bone fragments may heal improperly and limit the treatment outcome [1,2]. It is therefore necessary to identify the difficulties and limitations of closed treatment due to post-traumatic malocclusion [1-3].

Although three-dimensional computed tomography (3D-CT) is essential for imaging maxillofacial fractures, it cannot visualize bone fragments prior to the occurrence of trauma. The aim of this study was to identify prognostic indicators of malocclusion in patients who had undergone closed treatment, and to assess the utility of accurate morphometry using a novel 3D-CT approach for this purpose.

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Closed treatment
Closed treatment was performed for patients with traumatic occlusal deviation who provided informed consent, and also those with bilateral dentition allowing maxillomandibular fixation (MMF) and assessment of the occlusal relationship. Those undergoing MMF with elastics or wires using surgical brackets, MMF screws, or arch bars were evaluated. Occlusal deviation was stabilized using maxillomandibular elastic traction for approximately 1 week. Patients underwent MMF for 1-2 weeks. The MMF device was removed at 1-2 months after closed treatment, and the patients then underwent functional therapy including jaw movement exercises. For other concomitant maxillomandibular fractures, ORIF after maxillomandibular traction was performed. All treatments were performed by four oral surgeons, each with >7 years of experience.

Multislice CT imaging
Aquilion TSX-101A and TSX-101-H scanners (Toshiba Medical Systems, Otawara, Japan) were used to acquire multislice CT images employing the following parameters: detector coverage, 100-120 mm; 512 × 512 matrix with a 16-cm field of view; section thickness and interval, 0.5 mm.

Identification of prognostic factors
Malocclusion was examined statistically in relation to sidedness, the presence of other maxillomandibular fractures, and the MacLennan classification [4].

Accurate morphometry using 3D-CT a combination of pre-trauma, post-trauma, and after-healing images
Of the 74 patients who underwent closed treatment, 41 (56 sides) underwent CT scans to confirm bone fusion following treatment. However, some of the patients’ stored CT images had a large slice width, and therefore could not be reconstructed and analyzed accurately. The images obtained by separating the condyle from the glenoid in the 3D-constructed images were used in this study. Hence, morphometry was performed for 19 patients with confirmed bone fusion on the edited CT scans at 6.1 ± 1.8 months after treatment (11 unilateral and eight bilateral cases). Using 3D visualization software (Mimics Innovation Suite, Materialise, Leuven, Belgium), pre-trauma, post-trauma, and after-healing 3D-CT images were constructed (Fig. 1A). Bone fragments at the time of trauma were reduced using pre-trauma reconstructed 3D-CT images (Fig. 1Ac). The pre-trauma, post-trauma, and after-healing 3D-CT images were merged (Fig. 1B). Morphometry was then performed using 3D facial surgery planning software (ProPlan CMF, Materialise) (Fig. 1C-E). Pre-trauma, post-trauma, and after-healing loss of ramus height (LRH) (Fig. 1C), inclination angle (IA) of bone fragments (Fig. 1D), and lateral movement length (LML) (Fig. 1E) were measured. To evaluate the LRH, the condylar vertex points in each temporal image were marked, with the plane connecting the bilateral mandibular angle points set perpendicularly (Fig. 1C). The height of the mandibular ramus was calculated as the vertical distance from this plane to each vertex point, and the reductions in height from pre-trauma to post-trauma and after-healing trauma were measured. IA was measured using a straight line connecting the midpoint of the epiphysis of the fractured mandible to the vertex of the condyle before trauma and its vertex after trauma and after healing (Fig. 1D). To measure LML, a straight line connecting the vertex of the pre-trauma condyle to the midpoint of the epiphysis of
the fractured mandible was compared to the vertical distance of the vertex to the epiphysis after trauma and after healing (Fig. 1E). Morphological measurements were confirmed by three oral surgeons with 17-31 years of experience.

**Statistical analysis**

The statistical significance of differences in the appearance of malocclusion between unilateral and bilateral fractures, with and without other maxillomandibular fractures, and with and without displacement-deviation, was determined using Fisher’s exact test. The statistical significance of 3D-CT measurement accuracy was determined using Student’s t-test. Statistical significance was considered at \( P < 0.05 \). The comparison data met the criteria for normality and homogeneity of variance (\( P > 0.05 \); Shapiro-Wilk test and F-test). When normality was \( P > 0.05 \) but homoscedasticity was \( P < 0.05 \), Welch’s test was performed. When the normality was \( P < 0.05 \), the Mann-Whitney U-test was performed. All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Shimotsuke, Japan).

**Results**

**Identification of prognostic indicators of malocclusion after closed treatment**

The malocclusion types included were (1) a mild small-range anterior open bite, (2) moderate anterior open bite, or (3) severe midline shift and open bite. The frequency of occurrence of these malocclusions was 9.5\% in patients with condylar fractures, 2.1\% in unilateral cases, and 22.2\% in bilateral cases. There was a statistically significant difference in the frequency of malocclusion between bilateral and unilateral cases (\( P = 0.008 \)) (Fig. 2A).

In cases of unilateral condylar fracture, one patient with other maxillomandibular fractures had malocclusion; however, malocclusion was observed in 50.0\% of cases of bilateral fracture. Bilateral fractures revealed significant differences in the presence or absence of other maxillomandibular fractures (\( P = 0.003 \)) (Fig. 2B) and in patients with displacement-dislocation on either side (\( P = 0.044 \)) (Fig. 2C).

**Accurate morphometry using 3D-CT images**

The characteristics of the patients who underwent accurate morphometry measurements are presented in Table 1. Between patients with accurate morphometry and those with total closed treatment, there were no significant differences in age (\( P = 0.952 \)), gender (\( P = 0.796 \)), sidedness (unilateral/ bilateral) (\( P = 0.597 \)), site (head-upper neck/lower neck-subcondyle) (\( P = 0.395 \)), additional maxillomandibular fracture (\( P = 0.286 \)), and MacLennan classification (no displacement-deviation/displacement-dislocation) (\( P = 1.000 \)). LRH was 2.9 ± 2.1 mm for unilateral fractures and 3.6 ± 2.9 mm for bilateral fractures at the time of trauma (\( P = 0.446 \)), and 4.1 ± 3.1 mm for unilateral fractures and 4.1 ± 2.9 mm for bilateral fractures after healing (\( P = 0.951 \)) (Fig. 3A). The IA of the bone fragment at the time of trauma was 23.2 ± 13.1° and 26.5 ± 16.5° for unilateral and bilateral fractures, respectively (\( P = 0.587 \)), and 18.6 ± 12.6° and 25.4 ± 13.7° for the respective fractures after healing (\( P = 0.204 \)) (Fig. 3B). LML at the time of trauma was 8.5 ± 3.7 mm and 10.0 ± 7.7 mm for unilateral and bilateral fractures, respectively (\( P = 0.552 \)), and 8.9 ± 4.8 mm and 10.4 ± 7.7 mm for unilateral and bilateral fractures, respectively, after healing (\( P = 0.575 \)) (Fig. 3C).

The measurements for malocclusion in cases of bilateral fracture were then examined. The LRH values with and without malocclusion at the time of trauma (5.5 ± 3.3 mm and 2.5 ± 2.0 mm, respectively) and after healing (6.1 ± 1.8 mm and 3.0 ± 2.8 mm, respectively) were statistically significant (\( P = 0.035 \) and \( P = 0.028 \), respectively) (Fig. 3D). The IAs in patients with and without malocclusion at the time of trauma (30.0 ± 12.2° and 24.3 ± 18.9°, respectively) and after healing (32.7 ± 14.2° and 21.1 ± 12.0°, respectively) were not significantly different (\( P = 0.528 \) and \( P = 0.102 \), respectively) (Fig. 3E). The LMLs in patients with and without malocclusion at the time of trauma (14.8 ± 6.9 mm and 7.1 ± 6.9 mm) and after healing (16.9 ± 4.0 mm and 6.5 ± 6.8 mm) were significantly different (\( P = 0.049 \) and \( P = 0.004 \), respectively) (Fig. 3F). The LRH values in patients with and without combined maxillomandibular fractures at the time of trauma (3.8 ± 2.3 mm and 3.4 ± 3.5 mm, respectively) and after healing (5.8 ± 2.6 mm and 2.5 ± 2.1 mm, respectively) only showed a statistically significant difference after healing depending on the pres-
ence or absence of combined fractures (P = 0.015) (Fig. 3G). Using the MacLennan classification, LRH values in the no displacement-deviation and displacement-dislocation groups at the time of trauma (2.6 ± 2.6 mm and 5.9 ± 2.1 mm, respectively) and after-healing (3.0 ± 2.6 mm and 6.8 ± 1.1 mm, respectively) showed a statistically significant difference (P = 0.029 and P = 0.013, respectively) (Fig. 3H).

Discussion

Post-traumatic malocclusion is one of the most serious complications after treatment of maxillofacial fractures [3]. Most patients with maxillofacial fractures have condylar fractures after orthognathic surgery for post-traumatic malocclusion [3]. The incidence of post-traumatic malocclusion after closed treatment is 0-20% [1,2]. Previous reports have shown that non-surgical treatment has a significantly greater rate of post-traumatic malocclusion in comparison to ORIF [5,6].

In the present study, prognostic factors for malocclusion after closed treatment for fractures, including bilateral fractures, other additional maxillofacial fractures, and displacement or dislocation fractures, were identified (Fig. 2). Previous reports have suggested that bilateral fracture cases had the most malocclusions, and most patients with malocclusion after condylar fracture who underwent orthognathic surgery had other concomitant maxillomandibular fractures [3,5]. The more displaced the bone fragments in a condylar fracture, the more adaptations are necessary for re-establishment of pre-traumatic occlusion [7]. Thus, the factors identified here are consistent with those in previous reports.

Some researchers have reported the application of 3D-CT measurements in cases of condylar fracture [8,9]. Zhou et al. found that when the IA of bone fragments was greater than 11° and the LRH was greater than 4 mm at the time of injury, the patients felt pain and maximum mouth opening was restricted [8]. Using 3D-CT, Chen et al. measured LRH and IA in reconstructed pre-trauma and post-trauma images and found that the measured values differed between two-dimensional (2D) coronal CT images and 3D-CT images, suggesting that 3D-CT analysis can provide more accurate morphology results than 2D analysis [9]. However, these reports did not identify prognostic indicators of malocclusion [8,9]. LRH was significantly increased in cases of bilateral malocclusion or bilateral malocclusion combined with other maxillomandibular fractures, suggesting that malocclusion was the result of masticatory muscles exceeding their ability to adapt to the new skeletal conditions after treatment (Fig. 3D, G) [10]. LML was significantly increased, as was LRH in patients with malocclusion (Fig. 3F). These data suggested that LML may be an important prognostic factor for malocclusion after treatment. Regarding IA, there was no significant difference in occlusal abnormalities in this study. Previous reports have shown that IA and LRH are proportional [8]. In this study, there were cases of displacement-dislocation with lateral override, and IA was small, but the LRH was large (Fig. 3E). Furthermore, the LRH was significantly increased compared to other cases (Fig. 3H). Although the number of cases in which morphological measurement was performed was limited in this study, novel findings related to the appearance of malocclusion after closed treatment were obtained.

This study of clinical prognostic indicators of malocclusion after closed treatment using a novel 3D-CT imaging approach has shown that the degrees of increase in LRH and LML are important in this context.

Acknowledgments

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Conflict of interest

None.

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