Clinical, retrospective case-control study on the mechanics of obstacle in mouth opening and malocclusion in patients with maxillofacial fractures

Hai-Hua Zhou1,2, Kun Lv1,2, Rong-Tao Yang1,2, Zhi Li1,2, Xue-Wen Yang1,2 & Zu-Bing Li1,2

This study aims to identify and distinguish various factors that may influence the clinical symptoms (limited mouth opening and malocclusion) in patients with maxillofacial fractures. From January 2000 to December 2009, 963 patients with maxillofacial fractures were enrolled in this statistical study to aid in evaluating the association between various risk factors and clinical symptoms. Patients with fractured posterior mandibles tended to experience serious limitation in mouth opening. Patients who sustained coronoid fractures have the highest risk of serious limitation in mouth opening (OR = 9.849), followed by arch fractures, maxilla fractures, condylar fractures, zygomatic complex fractures and symphysis fractures. Meanwhile, the combined fracture of zygomatic arch and condylar process results in normal or mild mouth opening. High risks of sustaining malocclusion are preceded by the fracture of nasal bone (OR = 3.067), mandible, condylar neck/base, combined fracture of zygomatic arch and condylar process, mandibular body, bilateral condylar, dental trauma, mandibular ramus, symphysis, mandibular angle and mid-facial. Patients who experienced serious limitation in mouth opening are treated with surgery more frequently (OR = 2.118). No relationship exists between the treatment options and the patients with malocclusion.

The primary goals in treating maxillofacial fractures are to establish and maintain normal occlusion and attain the preinjury mobility and function of the jaws and the preinjury 3-dimensional (3D) facial contours1,2. Numerous studies have been conducted on the epidemiology and treatment of maxillofacial fractures. However, works on the basic mechanism of clinical symptoms, such as limited mouth opening and malocclusion, are limited; for instance, why different types of maxillofacial fractures display different symptoms in mouth opening and occlusion. In clinical practice, on the basis of experience alone, the occurrence and type of maxillofacial fractures are difficult to determine. More seriously, maxillofacial fractures are difficult to treat effectively and accurately3. Accordingly, postponed or inappropriate intervention may lead to the malformation of osseous callus and soft tissue fibrosis4, and even the occurrence of facial deformity (facial depression5, temporomandibular joint ankylosis and micrognathia6).

In previous studies, we analysed the mechanisms in the production of mandibular fractures5,7–10 and evaluated various factors that are correlated with maxillofacial fractures11–15. In the present study, we attach more importance to the symptoms of patients who sustained maxillofacial fractures. The exploration and analysis of the mechanism of the clinical symptoms of maxillofacial fractures could provide an in-depth understanding of the mechanism of maxillofacial fractures for an accurate and effective assessment of the patients’ condition and treatment of maxillofacial fractures, while reducing the individual, family, social and national burden and promoting
the recovery of the patients’ daily life [communication (speech and facial expression), nutrition, breathing, hearing, vision and cosmetic consequences]17.

Materials and Methods

Ethics Statement. We conducted a hospital-based retrospective case-control study at Stomatology College and Hospital, Wuhan University, from January 2000 to December 2009. The protocol and the survey and consent forms were approved by the Institutional Review Board (IRB) of Wuhan University (approval number: 2018-B05). The written consents provided by the patients were waived by the approving IRB.

Patient Population and Data Collection. This study included patients with maxillofacial fractures who were admitted at their initial visit to the Department of Oral and Maxillofacial Surgery, Stomatology College and Hospital, Wuhan University, from January 2000 to December 2009. Patients were excluded as study subjects based on the following: (1) Repeated admissions, (2) Incomplete information, (3) Maxillofacial fractures previously treated surgically in other hospitals. Data on age, sex, trauma etiologies, soft tissue injuries, dental trauma, general injuries (including traumatic head injuries and ocular trauma), malocclusion, maxillofacial fracture type, treatment delay times and treatment methods were collected and standardized by an investigator based on the patients’ case histories, clinical and radiographic examinations and medical records.

The injury mechanisms were classified as assault, road traffic accident (motor vehicle accident (MVA), motorcycle accident and bicycle accident), fall (at ground or high levels), sports- or work-related accident and others.

Mandibular fractures were classified as condylar (condylar head/comminuted, condylar neck, condylar base fractures), symphysis, body, angle, ramus, coronoid and alveolar fractures. Mid-facial fractures included zygomatic complex fracture (ZGF), zygomatic arch, Le Fort (I/II/III), nasal, orbital, maxilla and alveolar fractures.

Facial fractures were categorized as multiple or single mid-facial fractures (zygomatic arch, zygomatic complex, orbital, maxilla and upper alveolar fractures), combined fractures of the mid-face and mandible, multiple and single mandibular fractures, unilateral/bilateral condylar fractures, combined fractures of the condyle and zygomatic arch.

Critical clinical symptoms included limited mouth opening and malocclusion (inadequate restoration of occlusal relationships/persistent occlusal change18, including anterior open bite, lateral open bite, cross bite, mandibular retrognathia, maxillary retrognathia or laterognathia19, etc.). Soft tissue and/or dental injuries in the maxillofacial area were recorded. Associated fractures, such as skull, ocular, thoracic, cervical, vertebral, pelvic, extremity and abdominal injuries, were also documented as ‘other body fractures/injuries.’

The maximal mouth opening were measured with a ruler graded in millimeters according to Agerberg20 and Obwegeser et al.21. The patients were divided into the normal (opening > 3 cm), minor (2 cm < opening ≤ 3 cm), moderate (1 cm < opening ≤ 2 cm), severe (0.5 cm < opening ≤ 1 cm) and serious (opening ≤ 0.5 cm) groups.

Case and Control Groups. Cohort study 1: Patients diagnosed with limited mouth opening comprised the case group. Meanwhile, patients without limited mouth opening comprised the control group.

Cohort study 2: Patients diagnosed with malocclusion comprised the case group. Meanwhile, patients without malocclusion comprised the control group.

Statistical Analysis. Statistical analysis was performed using the SPSS software (version 19.0; SPSS, Chicago, IL, USA). Continuous variables were reported as mean ± SD and assessed using independent sample t-tests as necessary. The chi-square test was used to compare the categorical variables. Fisher’s exact test was utilized when observation in any cell of the 2 × 2 table was expected to be less than five. Odds ratio (OR) and 95% confidence interval (CI) were used to assess the risk of patients who sustained limited mouth opening or malocclusion. The risk factors of limited mouth opening were further analysed by using ordinal logistic regression. Logistic regression analysis was utilized to control the confounding variables. Probabilities of P < 0.05 were considered significantly different.

Results. The risks of patients who sustained serious limited mouth opening according to various variables are summarized in Table 1 (ordinal logistic regression). Patients who sustained fractures of the posterior mandible tended to be associated with serious limitation in mouth opening (coronoid fracture: OR = 2.989; condylar fracture: OR = 2.570; ramus fracture: OR = 1.592), compared with patients who sustained fractures of the anterior mandible (alveolar fracture: OR = 1.567; symphysis fracture: OR = 1.297; body fracture: OR = 1.225), except angle fractures (OR = 1.249) and condylar head fractures (OR = 1.206).

The relationship between various etiologies and the risk of limited mouth opening is further summarized in Table 2. Patients who sustained coronoid fractures had the highest risk of serious limitation in mouth opening (OR = 9.849), followed by arch fractures (OR = 3.202), maxilla fractures (OR = 2.914), condylar fractures (OR = 2.764), ZGF fractures (OR = 2.701) and symphysis fractures (OR = 2.694). As far as traumatic etiologies, such as assault, bicycle and MVA, are concerned, most of the patients tended to sustain moderate mouth opening (1 cm < opening ≤ 2 cm, OR > 1) and less probability of serious limitation in mouth opening (opening ≤ 0.5 cm, OR < 1). Patients with condylar neck/base fractures were more prone to the occurrence of mild mouth opening (OR > 1) and less to the occurrence of severe or serious limitation in mouth opening (OR < 1).

Interestingly, fracture of the zygomatic arch or condylar process resulted in the high occurrence of serious limitation in mouth opening (OR > 1), whereas the combined fracture of zygomatic arch and condylar process were more prone to normal or mild mouth opening (OR by ordinal logistic regression: 0.558; OR by logistic regression analysis: 0.568). Furthermore, patients who sustained serious limitation in mouth opening were treated by surgery more frequently (OR = 2.118), whereas patients with normal mouth opening were frequently treated nonsurgically.
| Factors | Case | Control | p     | OR  | 95% C.I. | Lower | Upper |
|---------|------|---------|-------|-----|----------|-------|-------|
| y = 1   | 44   | 919     | 0.000 | 0.059 | 0.017    | 0.204 |
| y = 2   | 252  | 711     | 0.420 | 0.610 | 0.183    | 2.032 |
| y = 3   | 436  | 527     | 0.009 | 4.968 | 1.484    | 16.643 |
| y = 4   | 51   | 912     | 0.000 | 30.054| 8.732    | 103.338 |
| Location|       |         |       |     |          |       |       |
| Malocclusion x1 | 601 | 362 | 0.732 | 0.952 | 0.725 | 1.251 |
| Mandibular fractures x2 | 760 | 203 | 0.572 | 1.332 | 0.493 | 3.600 |
| Single mandibular fracture x3 | 332 | 631 | 0.346 | 1.293 | 0.757 | 2.208 |
| Multiple mandibular fractures x4 | 428 | 535 | NA | NA | NA | NA |
| Condylar fractures x5 | 471 | 492 | 0.009 | 2.370 | 1.246 | 4.509 |
| Condylar head fractures/comminuted fractures x6 | 243 | 720 | 0.420 | 1.206 | 0.765 | 1.900 |
| Condylar neck/base fractures x7 | 261 | 702 | 0.030 | 0.612 | 0.393 | 0.953 |
| Bilateral condylar fractures x8 | 168 | 795 | 0.177 | 0.742 | 0.481 | 1.145 |
| Unilateral condylar fracture x9 | 303 | 660 | NA | NA | NA | NA |
| Mandibular angle fracture x10 | 116 | 847 | 0.437 | 1.249 | 0.713 | 2.184 |
| Mandibular body fracture x11 | 178 | 785 | 0.429 | 1.225 | 0.741 | 2.026 |
| Sympyysis fracture x12 | 347 | 616 | 0.261 | 1.297 | 0.824 | 2.042 |
| Alveolar fracture in mandible x13 | 11 | 952 | 0.457 | 1.567 | 1.246 | 4.509 |
| mandibular ramus fracture x14 | 13 | 950 | 0.403 | 1.592 | 0.535 | 4.740 |
| Coronoid fracture x15 | 22 | 941 | 0.020 | 2.989 | 1.199 | 7.508 |
| Mid-facial fractures x16 | 375 | 588 | 0.067 | 0.678 | 0.217 | 1.052 |
| Single mid-facial fractures x17 | 95 | 868 | 0.244 | 1.467 | 0.770 | 2.795 |
| Multiple mid-facial fractures x18 | 280 | 683 | NA | NA | NA | NA |
| Zygomatic arch fracture x19 | 237 | 726 | 0.001 | 2.312 | 1.425 | 3.747 |
| Zygomatic complex fractures x20 | 267 | 696 | 0.304 | 1.344 | 0.765 | 2.363 |
| Maxilla fracture x21 | 122 | 841 | 0.087 | 1.508 | 0.942 | 2.416 |
| Alveolar fracture in upper jaw x22 | 31 | 932 | 0.741 | 1.133 | 0.541 | 2.370 |
| Orbital fracture x23 | 128 | 835 | 0.857 | 1.042 | 0.666 | 1.629 |
| Nasal fracture x24 | 42 | 921 | 0.472 | 1.288 | 0.645 | 2.570 |
| Lefort I/II/III fractures x25 | 36 | 927 | 0.405 | 0.726 | 0.342 | 1.543 |
| Fracture of mid-facial and mandible x26 | 172 | 791 | NA | NA | NA | NA |
| Fracture of condyle and zygomatic arch x27 | 32 | 931 | 0.170 | 0.558 | 0.242 | 1.284 |
| Dental injuries x28 | 409 | 554 | 0.275 | 0.863 | 0.663 | 1.124 |
| Other body fractures/injuries (including traumatic head injuries or ocular injuries) x29 | 170 | 793 | 0.031 | 1.559 | 1.042 | 2.333 |
| Associated with traumatic head injuries x30 | 76 | 887 | 0.731 | 0.908 | 0.524 | 1.575 |
| Associated with traumatic ocular injuries x31 | 170 | 793 | 0.038 | 1.523 | 1.024 | 2.266 |
| Soft tissue injuries x32 | 739 | 224 | 0.279 | 1.182 | 0.874 | 1.597 |
| Surgical treatment x33 | 927 | 36 | 0.423 | 0.770 | 0.406 | 1.459 |
| Sex x34 | 753 | 210 | 0.673 | 0.938 | 0.698 | 1.262 |
| Age x35 | 519 | 0.997 | 0.988 | 1.006 |
| Treatment delay time x36 | 0.002 | 0.993 | 0.989 | 0.997 |
| Assault related accidents x37 | 128 | 835 | 0.647 | 0.825 | 0.362 | 1.878 |
| Bicycle accidents x38 | 59 | 904 | 0.369 | 0.658 | 0.264 | 1.637 |
| MVA x39 | 297 | 666 | 0.966 | 0.983 | 0.441 | 2.190 |
| Fall at ground level x40 | 129 | 834 | 0.261 | 0.617 | 0.266 | 1.430 |
| Fall from high x41 | 108 | 855 | 0.662 | 1.212 | 0.511 | 2.872 |
| Motorcycle x42 | 151 | 812 | 0.694 | 0.847 | 0.371 | 1.935 |
| Other x43 | 48 | 915 | 0.281 | 0.599 | 0.236 | 1.519 |
| Sport related accidents x44 | 19 | 944 | 0.805 | 1.156 | 0.366 | 3.651 |
| Work related accidents x45 | 24 | 939 | NA | NA | NA | NA |

**Table 1.** Evaluation of risk factors in patients with limited mouth opening by ordinal logistic regression. Y = 1: normal group (opening > 3 cm); Y = 2: minor group (2 cm < opening ≤ 3 cm); Y = 3: moderate group (1 cm < opening ≤ 2 cm); Y = 4: severe group (0.5 cm < opening ≤ 1 cm); NA: not application; MVA: motor vehicle accidents.
The risk of sustaining malocclusion in associated with different factors, which are summarized in Table 3. We found that nearly all traumatic factors had a high risk of occurrence of malocclusion (OR > 1), except for patients who sustained fractures of the condylar head/mandibular alveolar/zygomatic arch/coronoid process/maxilla alveolar/single mandible/single maxilla. The high risks of sustaining malocclusion in descending order are as follows: fracture of nasal bone (OR = 3.067), mandible (OR = 2.721), condylar neck/base (OR = 2.173), combined fracture of zygomatic arch and condylar process (OR = 1.846), mandibular body (OR = 1.731), bilateral condylar (OR = 1.595), dental trauma (OR = 1.564), mandibular ramus (OR = 1.432), symphysis (OR = 1.338), mandibular angle (OR = 1.330) and mid-facial (OR = 1.249). Interestingly, body injuries (including traumatic head and ocular injuries) resulted in the high occurrence of malocclusion (OR > 1). Heavy impact damages (motor vehicle accidents or motorcycle accidents) also resulted in the high occurrence of malocclusion (OR > 1). Interestingly, fractures of the zygomatic arch resulted in the low occurrence of malocclusion (OR = 0.452).

No relationship exists between the treatment delay times and the clinical symptoms of limited mouth opening or malocclusion, regardless of the length of time that passed after the fracture of the upper and lower jaws (Tables 1 to 3, OR ≈ 1). No relationship exists between the treatment options and the patients with malocclusion (Table 3, OR = 1.011).

Discussion. The movement of the mandible (mouth opening and closing) is controlled by several muscles that are attached to it. The masticatory muscles (from the zygomatic arch, inserted to the lateral aspect of ramus), temporalis (from the temporal lines of the parietal bone, inserted to the coronoid process and anterosuperior border of ramus) and medial pterygoid (from the pterygoid process and tuberosity, inserted to the medial aspect of ramus) control the elevation of mandible, while the medial and lateral pterygoids (from the pterygoid process, pyramidal process of palatine bone and tuberosity, inserted to the condyle and anteromedial part of the disk) control the protrusion and laterotrusion of the mandible. As the antagonism mechanisms, the temporalis controls the mandible retrusion, while the suprathyroid musculature controls the mandible decline. However, the occurrence of maxillary or mandible fracture (or injury) leads to broken muscle balance and the change in the movement mechanism of the mandible. A comprehensive understanding of the various factors that influence the movement of mandible after maxillofacial trauma is important in providing clinical and research data for the effective management of these injuries.

The fracture of condylar process results in high risk of serious limitation in mouth opening. However, further study revealed that the condylar head leads to the high occurrence of serious or severe limitation in mouth opening, whereas condylar neck/base fracture does not affect mouth opening. These phenomena may be attributed to several reasons. The articular disk is attached to the medial and lateral poles of the condylar process, ensuring the synchronized movements of the condyle and disk during gliding movements; however, in patients with condylar head fractures, the continued traction of the lateral pterygoid muscle results in the anteromedial displacement of the fragment in condylar head fractures, which may impede the movement of the condylar head. Condylar neck/base fractures destroy the integrity of the mandible, and the muscle tension of the articular disk and lateral pterygoid cannot perform the function of mandibular movement. Consequently, the gliding movements, protrusion and laterotrusion movement of the mandible are weakened. However, the descending movement of the mandible that is controlled by the suprathyroid musculature remains, and mouth opening is recovered with the weakening of edema and muscle spasms. Interestingly, the present study revealed that patients with bilateral condylar fractures are more prone to the occurrence of mild mouth opening. We propose that mandible movement that is centred by the mandibular foramen (a fulcrum, controlled by sphenomandibular ligament) is retained despite of the disappearance of the temporomandibular joint activity.

Patients who sustained condylar or zygomatic arch fractures are the most prone to serious limitation in mouth opening. Coronoid fractures seem highly co-related to zygomatic arch fractures. Our previous study revealed that majority of the patients who sustained coronoid fractures also had fractured zygomatic arches (20 of 25 patients, 80%). Furthermore, nearly all patients (23 of 25 patients, 92%) with coronoid fractures showed limited mouth opening. We propose that the fracture of the zygomatic arch or coronoid processes is usually attributed to the muscle compression or mechanical barrier in the process of mouth opening and closing, thus leading to the serious limitation in mouth opening. The masticatory muscles and temporalis are squeezed by the fracture of the zygomatic arch or coronoid process, resulting in reduced or dysfunctional muscle in the traction and shrinking process. In our experience, coronoid fracture removal is usually conducted when limited mouth opening cannot be resolved after the open reduction of maxillofacial fractures.

The fracture of mandible seems more prone to the limited mouth opening than mid-facial fractures, except for the fracture of the zygomatic arch. Additionally, patients with fractured posterior mandibles are prone to serious limited mouth opening compared with the patients with fractured anterior mandibles. This is understandable because most of the muscles (masticatory muscles, temporalis, medial pterygoid and lateral pterygoid) control the movement of the mandible attached to the posterior mandible. Interestingly, for patients who sustained serious limited mouth opening are concerned, the possibility of surgical treatment is high (OR = 2.118). The risk of surgical treatment dropped to 0.703-fold for patients with normal mouth opening. This phenomenon explains the main purpose of surgical treatment is to recover normal mouth opening. Thus, in the present study, surgical treatment is considered for patients with fractured mandibles compared to patients with mid-facial fractures, especially for patients with fractured posterior mandibles.

Malocclusion common in patients with fractured mandibles, except those with fractured coronoid process/condylar head/mandibular alveolar. Patients with mid-facial fractures have no obvious relationship with malocclusion. This is not surprising because the porous structure of the mid-face lowers the risk of malocclusion in patients with sustained mid-facial fractures (OR_{zygomatic arch} = 0.452, OR_{ZCF} = 1.051, OR_{maxilla} = 1.086, OR_{ramus} = 1.037 and OR_{Lefort I} = 1.253). In clinical practice, we rarely find situations where the dental arch is
Factors | Serious group (opening ≤ 0.5 cm) OR | Severe group (0.5 cm < opening ≤ 1 cm) OR | Moderate group (1 cm < opening ≤ 2 cm) OR | Minor group (2 cm < opening ≤ 3 cm) OR | Normal group (opening > 3 cm) OR
--- | --- | --- | --- | --- | ---
Malocclusion | x1 0.683 | 1.037 | 0.960 | 1.266 | 0.477
Mandibular fractures | x2 0.271 | 1.232 | 1.496 | 1.608 | 0.287
Single mandibular fracture | x3 1.520 | 1.281 | 0.969 | 0.826 | 0.434
Multiple mandibular fractures | x4 NA | NA | NA | NA | NA
Condylar fractures | x5 2.764 | 1.936 | 1.328 | 0.300 | 1.290
Condylar head fractures/comminuted fractures | x6 1.187 | 1.288 | 0.933 | 0.824 | 1.652
Condylar neck/base fractures | x7 0.363 | 0.589 | 0.868 | 1.672 | 0.556
Bilateral condylar fractures | x8 0.972 | 0.757 | NA | NA | NA
Unilateral condylar fracture | x9 NA | NA | NA | NA | NA
Mandibular angle fracture | x10 0.450 | 1.039 | 1.717 | 0.526 | 0.340
Mandibular body fracture | x11 1.163 | 1.197 | 1.075 | 0.747 | 0.907
Sympysis fracture | x12 2.694 | 1.046 | 1.031 | 0.759 | 0.680
Alveolar fracture in mandible | x13 — | 1.141 | 2.192 | 0.500 | —
Mandibular ramus fracture | x14 — | 1.599 | 1.570 | 0.414 | —
Coronoid fracture | x15 9.849 | 1.612 | 0.621 | 0.458 | —
Mid-facial fractures | x16 0.072 | 0.843 | 1.050 | 2.042 | 1.033
Single mid-facial fractures | x17 2.070 | 1.304 | 1.179 | 0.382 | 2.527
Multiple mid-facial fractures | x18 NA | NA | NA | NA | NA
Zygomatic arch fracture | x19 3.202 | 1.461 | 1.455 | 0.404 | 0.719
Zygomatic complex fractures | x20 2.701 | 0.936 | 1.285 | 0.594 | 1.100
Maxilla fracture | x21 2.914 | 1.082 | 0.918 | 0.655 | 1.123
Alveolar fracture in upper jaw | x22 — | 1.995 | 0.719 | 0.739 | 1.023
Orbital fracture | x23 0.888 | 1.099 | 1.084 | 0.767 | 1.604
Nasal fracture | x24 0.522 | 1.125 | 1.236 | 1.054 | 0.367
Lefort I/II/III fractures | x25 1.812 | 0.389 | 1.444 | 0.650 | 5.512
Fracture of mid-facial and mandible | x26 NA | NA | NA | NA | NA
Fracture of condyle and zygomatic arch | x27 1.218 | 0.908 | 0.387 | 2.956 | 2.020
Dental injuries | x28 0.885 | 0.925 | 0.904 | 1.118 | 1.339
Other body fractures/injuries (including traumatic head injuries or ocular injuries) | x29 2.054 | 1.386 | 1.013 | 0.674 | 0.640
Associated with traumatic head injuries | x30 1.271 | 1.108 | 0.526 | 1.713 | 1.260
Associated with traumatic ocular injuries | x31 2.085 | 1.753 | 0.624 | 1.156 | 0.478
Soft tissue injuries | x32 0.927 | 1.120 | 1.112 | 0.805 | 0.949
Surgical treatment | x33 2.118 | 0.520 | 1.093 | 1.553 | 0.703
Sex | x34 0.729 | 0.990 | 1.041 | 1.002 | 1.241
Age | x35 1.002 | 1.000 | 1.001 | 0.998 | 0.998
Treatment delay time | x36 1.014 | 1.004 | 1.004 | 0.996 | 0.987
Assault related accidents | x37 0.114 | 0.725 | 2.066 | 1.257 | 0.112
Bicycle accidents | x38 0.307 | 0.453 | 2.183 | 1.136 | 0.428
MVA | x39 0.394 | 0.657 | 2.328 | 0.834 | 0.225
Fall at ground level | x40 0.325 | 0.332 | 2.586 | 1.031 | 0.485
Fall from high | x41 0.491 | 0.569 | 3.178 | 0.682 | 0.047
Motorcycle | x42 0.184 | 0.491 | 3.451 | 0.806 | 0.153
Other | x43 0.142 | 0.513 | 1.589 | 1.989 | 0.166
Sport related accidents | x44 0.510 | 0.550 | 3.539 | 0.649 | —
Work related accidents | x45 NA | NA | NA | NA | NA

Table 2. Multivariate logistic regression analysis of patients with limited mouth opening. Note: OR = odds ratio; 95% confidence interval was not listed.

Divided into several sections in the upper jaws of patients with mid-facial fractures. Patients who sustained heavy impact damage (from motor vehicle accidents or motorcycle accidents) are more prone to malocclusion; however, no relationship exists between the heavy impact damage and the limitation in mouth opening. Interestingly, patients with other body fractures/injuries (including traumatic head injuries or ocular injuries) are more prone to both malocclusion and serious limited mouth opening.

Patients with different fracture levels of the mandibular condylar process display different clinical symptoms. Patients with condylar base/neck fractures are more prone to malocclusion than to limited mouth opening. In contrast, patients with condylar head fractures show high occurrence of limited mouth opening than malocclusion. In the present study, we found that patients who sustained serious limited mouth opening were treated by surgery more frequently (OR > 1), whereas patients with normal mouth opening were more frequently treated by nonsurgical approaches. Accordingly, the surgical treatment of condylar head fractures is considered more frequently than before. In fact, increasing studies are reporting good results and advantages of the surgical treatment.
of condylar head fractures. In our past experience, the majority of condylar head fractures were treated by surgical procedures. For patients with linear condylar base/neck fractures (nondisplaced or mild displacement), intermaxillary traction (non-surgical treatment) was considered first; surgical procedure was considered once the malocclusion could not be resolved by intermaxillary traction or if patients sustained serious dislocated fractures of the condylar base/neck.

In the present study, we found that no relationship exists between the treatment delay time (old or new fracture) and the clinical symptoms of limited mouth opening or malocclusion. Thus, early intervention of the patients with symptoms of limited mouth opening or mal occlusion is important, patients should not depend on

Table 3. Multivariate logistic regression analysis of patients with malocclusion.

| Factors                                                   | Case (n = 601) | Control (n = 362) | 95% C.I.      |
|-----------------------------------------------------------|----------------|------------------|---------------|
| Limited mouth opening                                     | x1 1.86 ± 0.756 | 1.87 ± 0.861      | 0.847 0.981 1.080 1.192 |
| Mandibular fractures                                      | x2 5.30 | 2.30 | 0.159 2.721 0.675 10.971 |
| Single mandibular fracture                                | x3 1.88 | 1.44 | 0.097 0.532 0.253 1.121 |
| Multiple mandibular fractures                             | x4 NA | NA | NA NA NA NA |
| Condylar fractures                                         | x5 3.46 | 1.25 | 0.947 1.031 0.417 2.552 |
| Condylar head fractures/commminated fractures             | x6 1.65 | 0.76 | 0.429 0.772 0.407 1.465 |
| Condylar neck/base fractures                               | x7 2.10 | 0.51 | 0.013 2.173 1.180 4.002 |
| Bilateral condylar fractures                               | x8 1.39 | 0.99 | 0.147 1.595 0.849 2.996 |
| Unilateral condylar fracture                              | x9 NA | NA | NA NA NA NA |
| Mandibular angle fracture                                  | x10 0.80 | 0.36 | 0.470 1.330 0.614 2.885 |
| Mandibular body fracture                                   | x11 1.36 | 0.42 | 0.140 1.731 0.835 3.586 |
| Symphysis fracture                                         | x12 2.63 | 0.84 | 0.382 1.338 0.696 2.572 |
| Alveolar fracture in mandible                              | x13 0.6 | 5 | 0.302 0.474 0.155 1.958 |
| Mandibular ramus fracture                                  | x14 1.1 | 2 | 0.672 1.432 0.271 7.580 |
| Coronoid fracture                                          | x15 0.9 | 13 | 0.329 0.557 0.172 1.805 |
| Mid-facial fractures                                       | x16 1.89 | 1.86 | 0.664 1.249 0.458 3.403 |
| Single mid-facial fractures                                | x17 0.47 | 0.48 | 0.886 0.942 0.419 2.119 |
| Multiple mid-facial fractures                              | x18 NA | NA | NA NA NA NA |
| Syzygomatic arch fracture                                  | x19 9 | 0 | 0.007 0.452 0.255 0.803 |
| Syzygomatic complex fractures                              | x20 1.13 | 1.13 | 0.894 1.051 0.509 2.167 |
| Maxilla fracture                                           | x21 0.7 | 0.52 | 0.784 1.086 0.603 1.955 |
| Alveolar fracture in upper jaw                             | x22 0.17 | 0.14 | 0.695 0.833 0.334 2.078 |
| Orbital fracture                                           | x23 0.66 | 0.62 | 0.897 1.037 0.597 1.803 |
| Nasal fracture                                             | x24 0.30 | 0.12 | 0.012 3.067 1.284 7.329 |
| Lefort I/II/III fractures                                  | x25 0.24 | 0.12 | 0.639 1.253 0.489 3.209 |
| Fracture of mid-facial and mandible                        | x26 NA | NA | NA NA NA NA |
| Fracture of condyle and syzygomatic arch                   | x27 0.75 | 0.7 | 0.280 1.846 0.607 5.616 |
| Dental injuries                                            | x28 2.93 | 1.16 | 0.008 1.564 1.122 2.181 |
| Other body fractures/injuries (including traumatic head injuries or ocular injuries) | x29 1.24 | 0.46 | 0.067 1.650 0.965 2.823 |
| Associated with traumatic head injuries                    | x30 0.51 | 0.25 | 0.988 0.995 0.488 2.027 |
| Associated with traumatic ocular injuries                  | x31 0.79 | 0.91 | 0.168 0.708 0.433 1.157 |
| Soft tissue injuries                                       | x32 0.457 | 0.282 | 0.952 0.988 0.671 1.455 |
| Surgical treatment                                         | x33 0.580 | 0.347 | 0.978 1.011 0.459 2.228 |
| Sex (man)                                                  | x34 0.478 | 0.275 | 0.163 1.306 0.898 1.899 |
| Age                                                       | x35 30.24 ± 13.09 | 33.19 ± 13.77 | 0.028 1.013 1.001 1.025 |
| Treatment delay time                                       | x36 19.70 ± 29.56 | 18.60 ± 30.24 | 0.918 1.000 0.994 1.005 |
| Assault related accidents                                  | x37 0.71 | 0.57 | 0.873 1.085 0.400 2.945 |
| Bicycle accidents                                          | x38 0.33 | 0.26 | 0.774 0.849 0.278 2.596 |
| MVA                                                       | x39 1.93 | 1.04 | 0.398 1.529 0.571 4.089 |
| Fall at ground level                                       | x40 0.76 | 0.53 | 0.927 0.953 0.341 2.662 |
| Fall from high                                             | x41 0.82 | 0.26 | 0.949 0.966 0.332 2.814 |
| Motorcycle                                                | x42 0.97 | 0.54 | 0.375 1.583 0.574 4.367 |
| Other                                                      | x43 0.21 | 0.27 | 0.302 0.550 0.177 1.799 |
| Sport related accidents                                    | x44 0.52 | 0.7 | 0.635 0.715 0.179 2.857 |
| Work related accidents                                     | x45 NA | NA | NA NA NA NA |
self-recovery or automatic healing. A surgical treatment plan should be considered for patients who sustained serious limited mouth opening. For instance, patients with fractured coronoid process/symphysis/Lefort/combined body injuries (including traumatic head injuries or ocular injuries) (Table 2) and simultaneously associated with serious limited mouth opening should consider surgical treatment first. Patients who sustained only malocclusion could consider a non-surgical treatment procedure (intermaxillary traction and/or fixation of loose teeth).

We acknowledge some flaws in our study. As a retrospective clinical case-control study, the incomplete information collected results in part loss of sample subjects. Information were collected based on case histories, and thus the reliability of information is dependent on how accurately the patients provided the information and the standard uniform recording by different physicians. Additionally, we should point out that some kinds of malocclusion are present in populations without facial fractures, we also don't know if they had these malocclusions before the fractures occurred. However, a large sample size (963 patients) over a long period (10 years) may partially compensate for the above shortcomings. Regardless of this study's results, a prospective, multicentre/multilevel and large sample study should be conducted in the future.

The present study revealed that patients associated with serious limited mouth opening should prefer surgical procedure. Patients who sustained only malocclusion or acceptable/normal mouth opening may consider a non-surgical treatment procedure; nonetheless, the patient's appearance (3-dimensional facial contours) is also an important factor that needs to be considered. The accurate assessment of patients' condition are helpful in the timely, correct and effective treatment of the their disease, while reducing the individual, family, social and national burden. Such a retrospective study can be used to guide the future funding of public health programs that are geared towards the prevention and treatment of such injuries.

References
1. Ellis, E. & Miles, R. A. Fractures of the mandible: a technical perspective. Plast. Reconstr. Surg. 120, 765–895 (2007).
2. He, D., Zhang, Y. & Ellis, E. Panfacial fractures: analysis of 33 cases treated late. J. Oral. Maxil. Surg. 65, 2459–2465 (2007).
3. Li, Z., Zhang, W., Li, Z. B. & Li, J. R. Abnormal union of mandibular fractures: a review of 84 cases. J. Oral. Maxil. Surg. 64, 1225–1231 (2006).
4. Czerwinski, M., Parker, W. L., Correa, J. A. & Williams, H. B. Effect of treatment delay on mandibular fracture infection rate. Plast. Reconstr. Surg. 122, 881–885 (2008).
5. Zhou, H. H., Li, K., Yang, R. T., Li, Z. & Li, Z. B. Risk factor analysis and idiographic features of mandibular coronoid fractures: A retrospective case–control study. Sci Rep. 7, 2208 (2017).
6. Zhou, H. H., Han, J. & Li, Z. B. Conservative treatment of bilateral condylar fractures in children: Case report and review of the literature. Int. j. pediatr. otorhinolaryngol. 74, 1557–1562 (2014).
7. Zhou, H. H., Li, K., Yang, R. T., Li, Z. & Li, Z. B. Mechanics in the production of mandibular fractures: A clinical, retrospective case-control study. PloS one. 11, e0149553 (2016).
8. Zhou, H. H., Liu, Q., Cheng, G. & Li, Z. B. Aetiology, pattern and treatment of mandibular condylar fractures in 549 patients: a 22-year retrospective study. J. Cranio. Maxill. Surg. 41, 34–41 (2013).
9. Zhou, H. H., Ongodia, D., Liu, Q., Yang, R. T. & Li, Z. B. Dental trauma in patients with single mandibular fractures. Dent. traumatol. 29, 291–296 (2013).
10. Zhou, H. H., Hu, T. Q., Liu, Q., Ongodia, D. & Li, Z. B. Does trauma etiology affect the pattern of mandibular fracture? J. Cranio. Maxill. Surg. 23, e494–e497 (2012).
11. Zhou, H. H., Liu, Q., Yang, R. T., Li, Z. & Li, Z. B. Ocular trauma in patients with maxillofacial fractures. J. Cranio. Maxill. Surg. 25, 519–523 (2014).
12. Zhou, H. H., Liu, Q., Yang, R. T., Li, Z. & Li, Z. B. Traumatic head injuries in patients with maxillofacial fractures: a retrospective case–control study. Dent. traumatol. 31, 209–214 (2015).
13. Zhou, H. H., Ongodia, D., Liu, Q., Yang, R. T. & Li, Z. B. Incidence and pattern of maxillofacial fractures in children and adolescents: a 10 years retrospective cohort study. Int. j. pediatr. otorhinolaryngol. 77, 494–498 (2013).
14. Zhou, H. H., Liu, Q., Yang, R. T., Li, Z. & Li, Z. B. Maxillofacial fractures in women and men: a 10-year retrospective study. J. Oral. Maxil. Surg. 73, 2181–2188 (2015).
15. Zhou, H. H., Liu, Q., Yang, R. T., Li, Z. & Li, Z. B. Dental trauma in patients with maxillofacial fractures. Dent. traumatol. 29, 285–290 (2013).
16. Zhou, H. H., Ongodia, D., Liu, Q., Yang, R. T. & Li, Z. B. Changing pattern in the characteristics of maxillofacial fractures. J. Cranio. Maxill. Surg. 24, 929–933 (2013).
17. Bak, M. J. & Doerr, T. D. Craniomaxillofacial fractures during recreational baseball and softball. J. Oral. Maxil. Surg. 62, 1209–1212 (2004).
18. Silvennoinen, U., Iizuka, T., Oikarinen, K. & Lindqvist, C. Analysis of possible factors leading to problems after nonsurgical treatment of condylar fractures. J. Oral. Maxil. Surg. 52, 793–799 (1994).
19. Komers, S. C., van den Bergh, B., Boffano, P., Verweij, K. P. & Forouzanfar, T. Dysocclusion after maxillofacial trauma: a 42 year analysis. J. Cranio. Maxill. Surg. 42, 1083–1086 (2014).
20. Agerberg, G. Maximal mandibular movements in young men and women. Swed. dent. j. 67, 81–100 (1974).
21. Obwegeser, J. K., Farmhand, M., Al-Majali, F. & Engdekel, W. Findings of mandibular movement and the position of the mandibular condyles during maximal mouth opening. Oral Surg Oral Med Oral Pathol. 63, 517–525 (1987).
22. Von Arx, T. & Lozanoff, S. Clinical Oral Anatomy: A Comprehensive Review for Dental Practitioners and Researchers. (Springer, Press, 2016).
23. Vesnaveer, A. Open reduction and internal fixation of intra-articular fractures of the mandibular condyle: our first experiences. J. Oral. Maxil. Surg. 66, 2123–2129 (2008).
24. Hlawitschka, M., Loukota, R. & Eckelt, U. Functional and radiological results of open and closed treatment of intracapsular (diacapitular) condylar fractures of the mandible. Int. j. oral. max. sur. 34, 597–604 (2005).
25. Kermer, C. H., Undt, G. & Rasse, M. Surgical reduction and fixation of intracapsular condylar fractures: a follow up study. Int. j. oral. max. sur. 27, 191–194 (1998).

Acknowledgements
This work was supported by National Natural Science Foundation of China (Grant No. 81470718, Grant No. 81271107, Grant No. 81771051), the Wuhan Science and Technology Plan Project (Grant No. 2015061701011641).
Author Contributions
Conceived and designed the experiments: H.H.Z. Analysed the data: H.H.Z. Wrote the paper: H.H.Z. Substantial contribution to acquisition of data: H.H.Z. Critically revised article for important intellectual content: H.H.Z., K.L., R.T.Y., Z.L., X.W.Y., Z.B.L. Critically reviewed the manuscript: X.W.Y., Z.B.L. Approved the final version of the manuscript: X.W.Y., Z.B.L.

Additional Information
Competing Interests: The authors declare no competing interests.

Publisher’s note: Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

© The Author(s) 2018