Bite force, electromyography, and mandible mobility during the 6-month period after surgical treatment for isolated fractures of the zygomatico-orbital complex

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Objective. The aim of this study was to identify the behavior of masticatory muscles after fractures of the zygomatico-orbital complex (ZOC) and subsequent surgical treatment, by using analyses of bite force, electromyography (EMG), and mandible mobility during a 6-month period after surgery.

Study design. Five patients with fractured ZOCs treated surgically by using an intraoral approach and fixation exclusively in the region of the zygomaticomaxillary buttress were evaluated. The control group included 12 other patients. During postoperative follow-up, bite force, mandible mobility, and EMG analysis of the masticatory muscles were evaluated.

Results. There was an increase in bite force with time, but a decline in EMG activity during the same period. In the mandible mobility analysis, only maximum mouth-opening values increased significantly after the surgical treatment.

Conclusions. The masticatory musculature, according to bite force and EMG, returned to its normal condition by the second month after surgery, and maximum mouth opening was observed after the first month. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111:e1-e7)

The zygomatico-orbital complex (ZOC) is a prominent facial region consisting of direct connections among several bone processes (zygoma, maxilla, and sphenoid). Among facial fractures, it is the second most frequent to occur, with a 6:2:1 ratio compared with mandibular and maxillary fractures, respectively.1 The etiologic agents vary considerably and include motorcycle and car accidents, physical aggression, falls, and sports accidents.2 The treatment of facial fractures has advanced from the use of steel threads or rigid internal fixation devices (RIF) since the 1970s.3

Studies addressing masticatory muscles before and after orthognathic surgery are of great importance, particularly those on the masseter and temporal muscles.4 These studies include evaluations to measure the human bite force with the purpose of assessing and understanding the function of the stomatognathic system.5 Bite force is directly related to chewing and is determined by the mandible elevator muscles and regulated by the nervous, muscular, skeletal, and dental systems. Therefore, the condition of these systems affect an individual’s ability to chew and bite, especially when facial fractures are involved.1

Because the masticatory muscles are important for various functions of the stomatognathic system, the purpose of the present study was to measure the changes in the maximum bite force, electromyographic (EMG) activity, and mandibular mobility (the maximum amplitudes of protrusion, right and left lateral movement, and mouth opening) in patients surgically treated for a fractured ZOC solely by an intraoral approach and fixation of the zygomaticomaxillary buttress.

PATIENTS AND METHODS

Patient selection
The volunteers were comprehensively informed about the experiment and agreed to participate by providing signed informed consent for research, according to resolution 196/96 of the National Health Council, Brazil. The study was approved by the Ethics Committee of the Ribeirão Preto College of Dentistry of the University of São Paulo (process no. 2007.1.1371.58.2). According to the inclusion criteria, patients were required to have no comorbidities, have isolated ZOC fractures treated surgically with rigid
internal fixation, be available for follow-up, have Angle dental class I occlusion, and have all teeth (including second molars) in good condition. This final criterion allowed the examination to be performed on the load-application spots (regions of the molars on the ipsilateral and opposite side of the fracture and between the central incisors).

Patients were excluded from the study if they did not meet these requirements or if they presented extensive abrasions and lacerations on the face, which made it impossible to place the electrodes, or were unable to open their mouths widely. Therefore, considering the inclusion/exclusion criteria, at the beginning of the study 10 patients were diagnosed with fractures of the ZOC, but only 5 of them were included in the study.

Surgical procedure
The ZOC fractures were identified through clinical and imaging examinations and were classified according to the classification of Jackson.6 Four patients had type I fractures, and 1 patient had a type III fracture.

The surgical procedures were performed by the same team in the Oral and Maxillofacial Surgery Department at the School of Dentistry, University of São Paulo, in a hospital environment and with general anesthesia. Only intraoral access was used. Fracture fixation was performed using 2 systems of the same brand (Neortho), namely the 1.5-mm or 2.0-mm sizes, but only 1 location was selected for RIF application, i.e., the region of the zygomaticomaxillary buttress. In the postoperative period, patients were prescribed non-steroidal antiinflammatory medication for 3 days and analgesics for pain. All patients were discharged from hospital on the first day after surgery. No dietary restrictions were prescribed, and all patients received oral hygiene instructions.

Bite-force and EMG data
The patients were first submitted to a clinical examination to ensure satisfactory postoperative clinical progress. Next, patients were referred to the Electromyography Laboratory for bite-force measurements, EMG examinations, and analyses of mandibular mobility. These assessments were performed monthly for 6 months.

During this stage of the study, 50% of the patients left the study and did not attend the follow-up appointments. Therefore, the fractured ZOC patient group consisted of 5 patients (4 men and 1 woman) with 6 months of postoperative follow-up. Ages ranged between 17 and 63 years with an average age of 32 years. The control group, consisting of 12 individuals, 6 male and 6 female, with an average age of 20 years, was composed with the exclusive purpose of obtaining reference normality values to verify the progress of the patients submitted to surgery after facial trauma.

The EMG signals and bite-force measurements were collected with the volunteers sitting on a comfortable chair (office-like) with the arms extended along the body and their hands lying on their thighs. Bite-force measurements were recorded with digital dynamometers, model IDDK (Kratos, Cotia, São Paulo, Brazil), with a 100 kgf capacity, adapted to the mouth. The apparatus had a “set-zero” key, which allowed the exact control of the values obtained, and a “peak” register, which facilitated the recording of the maximum bite force during measurements. The dynamometer had 2 rods with plastic disks on each end, over which the bite force was applied. It had a high-precision charge cell and electronic circuit to indicate the force and supply precise measurements, easily viewed on a digital display. The dynamometer was cleaned with alcohol, and disposable latex finger cots (Wariper, São Paulo, Brazil) were positioned on the biting rods as biosafety measurements. The volunteers were given detailed instructions, and bite tests were performed before the actual recordings were made to ensure the reliability of the procedure. The volunteers were then asked to bite the dynamometer 3 times with maximum force, with 2-minute rest intervals between recordings. Evaluations were performed on the first molar (left and right) and central incisor regions.

Electromyography was performed using 5 channels of the Myosystem-Br1 apparatus (DataHominis, Uberlândia, Minas Gerais, Brazil). The electromyographic signals were analogically amplified with a gain of 1,000 × filtered with a pass-band of 0.01 to 1.5 kHz and sampled by a 12-bit A/D converter with a 2-kHz sampling rate. The signals were digitally filtered with a pass-band filter of 10-500 Hz during the data processing. Surface differential active electrodes (2 10-mm-long and 2-mm-wide silver-chloride bars, separated by a distance of 10 mm with an input impedance of 10 Ï and a common-mode rejection ratio of 130 dB at 60 Hz) were used in the study. The skin region where electrodes were placed was cleansed with alcohol and shaved when necessary. The differential active electrodes were positioned in the ventral region of both masseters and in the anterior portion of both temporal muscles. The position of the electrodes was determined by palpation, and they were adhered with adhesive bandage tape with the longest extension of the bars perpendicular to the direction of the muscle fibers. A stainless steel circular electrode (3 cm in diameter) was also used as a reference electrode (ground electrode), adhered to the skin over the frontal bone region.

The muscular activity was evaluated by using EMG recordings of the masticatory musculature at rest and
Data analyses

Statistical analyses were performed with SPSS software, version 17.0 (Chicago, IL), and the data on the bite force between the groups were analyzed using the repeated measures test. A 5% level of significance ($P \leq .05$) was adopted.

**RESULTS**

The control group used in this study presented, as an average of single measurement, the following bite-force values in the following regions: first molars on the right side, 54.26 kgf; first molars on the left side, 59.17 kgf; and incisors, 15.32 kgf. The EMG activities are shown in Table 1. As for mandibular mobility, the following measurements were obtained: mouth opening, 48.85 mm; right lateral movement, 8.9 mm; left lateral movement, 8.32 mm; and protrusion, 4.71 mm.

All patients reported paresthesia of the infraorbital nerve on the fractured side, with a mean duration of 2 months before full return to regular functioning, but the patients did not report diplopia or any restricted eye movement. As for the gender distribution, there were 4
men and 1 woman. Four patients had type I fractures, and 1 patient had a type III fracture, as classified according to Jackson. The etiologies of the traumas included motorcycle accidents, domestic accident, sports accident, and physical aggression. Regarding the side of the face that was fractured, 3 patients had their right side affected, whereas 2 were injured on the left side of the face (Table II), with no difference between the fractured sides in terms of the issues addressed in the present study. All procedures were completed without intra- or postoperative complications. All patients who underwent the surgical treatment (RIF) achieved satisfactory functional and esthetic outcomes, without sequelae.

The bite force in all measured regions, namely, the regions of the molars on the side of the fracture, those on the opposite side, and between the central incisors, increased during the 6-month period. In addition, the bite force assessment showed statistically significant differences compared with control subjects in all 3 regions in which bite force was recorded \((P < .05)\) until the second month after surgery, with a subsequent increase until the sixth month. The bite force of the first right molar was 41.04% that in the control group, increasing to 65.73% in the second month. For the first left molar, these values were 36.55% and 54.94%, respectively, and the values for the incisors were 53.0% and 73.89%, respectively (Table III).

On the other hand, EMG activity was high in the beginning and declined throughout the studied period. The same trend occurred for the masseter and temporal muscles bilaterally in the initial evaluations, at rest and during posture movements. A statistically significant difference was observed compared with the control group until the second month, but not after that period (Table I). In the mandibular mobility evaluation, only mouth opening increased with time, with a statistically significant difference compared with the control group until the second month after surgery. Right and left lateral movement and protrusion, on the other hand, showed no change during the studied periods (Table IV).

### DISCUSSION

There are few studies that address the masticatory musculature in patients with facial fractures. Predominantly, studies address this return to function by means of bite-force measurements in the pre- and postoperative periods relative to orthognathic surgery. \(^7\)–\(^10\)

Harada et al.\(^9\) reported that patients with prognathism submitted only to mandibular surgery using the technique of sagittal split osteotomy of the mandibular ramus showed reduced bite-force values in the postoperative period until the third month compared with preoperative values. These values increase until the sixth month, although the values are lower than those achieved by the control group. Harada et al.\(^9\) also reported that combined surgeries in Angle class III patients reduce the posterior facial height, implying reduced bite-force measurements during a 1-year period, compared with the group submitted only to mandibular surgery, despite an increase in that value with time.

Ohkura et al.\(^11\) also found that bite-force values increase with time in patients submitted to orthognathic surgery, although the patients did not achieve the same values as the control group during the 3-year period. This increased bite-force value was also observed by van den Braber et al.,\(^12\) but that study involved patients with retrognathism submitted to advancement using a sagittal technique with a 5-year follow-up. However, studies such as those by Throckmorton and Ellis\(^10\) affirm that the surgical procedure of orthognathics is not the factor responsible for these changes in bite force, and they report that the force measured during the preoperative period may be masked because the patient is under the influence of orthodontic forces that reduce bite force.

Regarding facial trauma, it is not possible to make comparisons involving preoperative measurements, and these patients must instead be studied over time and compared with a control group consisting of healthy individuals with normal occlusion and dentition. It is recognized that there is great variability in this type of study, because fractures are never identical and there is

### Table II. Sample distribution

<table>
<thead>
<tr>
<th>Etiology</th>
<th>Fractured side</th>
<th>Surgical access</th>
<th>RIF</th>
<th>Region of plate</th>
<th>Type of fracture</th>
<th>Gender</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Sports accident</td>
<td>Right</td>
<td>Intraoral</td>
<td>1.5 mm</td>
<td>Zygomatic buttress</td>
<td>Type I</td>
<td>M</td>
<td>24</td>
</tr>
<tr>
<td>2 Motorcycle accident</td>
<td>Right</td>
<td>Intraoral</td>
<td>2.0 mm</td>
<td>Zygomatic buttress</td>
<td>Type I</td>
<td>M</td>
<td>30</td>
</tr>
<tr>
<td>3 Accident with bamboo</td>
<td>Left</td>
<td>Intraoral</td>
<td>1.5 mm</td>
<td>Zygomatic buttress</td>
<td>Type I</td>
<td>F</td>
<td>63</td>
</tr>
<tr>
<td>4 Motorcycle accident</td>
<td>Left</td>
<td>Intraoral</td>
<td>1.5 mm</td>
<td>Zygomatic buttress</td>
<td>Type I</td>
<td>M</td>
<td>25</td>
</tr>
<tr>
<td>5 Physical aggression</td>
<td>Right</td>
<td>Intraoral</td>
<td>1.5 mm</td>
<td>Zygomatic buttress</td>
<td>Type III</td>
<td>M</td>
<td>17</td>
</tr>
</tbody>
</table>

**RIF**, Rigid internal fixation.
variation in etiology, among other factors. In addition to the difference in the fracture pattern from patient to patient, there are also differences regarding the ZOC and the types of fracture treatments used, which range from conservative treatments to the many possible surgical techniques with RIF. Considering that 4 of the 5 patients in the present study were classified as Jackson type I ZOC fractures, which represents minimally displaced fractures, the authors assumed the proposed treatment discussed by Ellis and Kittidumkeng, consisting of intraoperative assessment of stability of the repositioned ZOC and digital pressure used after reduction to determine the need for applying fixation devices. Fixation with 1 bone plate, either at the zygomaticomaxillary buttress or, more commonly, the frontozygomatic area, as performed successfully in several of their patients, has been advocated by others in a certain percentage of ZOC fractures. Further, as inherent to this classification, it is not required to surgically approach and reconstruct the orbital cavity in Jackson type I and III ZOC fractures. We agree with Ellis and Zide that the maxillary vestibular approach is one of the most useful when performing any of a wide variety of procedures in the midface. This approach allows relatively safe access to the entire facial surface of the midfacial skeleton, from the zygomatic arch to the infraorbital rim to the frontal process of the maxilla. The intraoral approach provides the exposure of the zygomaticomaxillary buttress, which is one of the most reliable areas in which to correctly reduce, align, and fix these fractures. The greatest advantage of the approach is the resulting hidden intraoral scar, thus producing better esthetic outcomes. Moreover, the approach is also relatively rapid and simple, and complications are few. Damage to branches of the facial nerve is nonexistent as long as 1 stays within the subperiosteal plane, and damage to the infraorbital nerve is unusual with proper technique.

The postoperative follow-up of patients in these studies is another important issue, because when patients find themselves fully recovered, they no longer return for reevaluations. Therefore, the follow-up data are useless, because a long-term evaluation was intended. Oyen and Tsay (1991) showed that the biomechanics of the ZOC are extremely complex, and they highlighted the presence of several muscles that originate in that region. They also demonstrated the transmission of greater forces to the region of the frontal process of the zygoma, with these forces being twofold greater on the working side compared with the balance side during mandible lateral movements.

In another study performed by Oyen et al. in monkeys, the authors showed that there was a transmission of forces to the ZOC, especially to the lateral wall of the orbital ridge, after the stimulation of maximum masticatory force in these animals. It was hypothesized that the masseter muscle could cause fracture instability in the postoperative period. However, dal Santo et al. and the present study, in clinical analyses, did not observe any facial asymmetry in the postoperative period, and patients did not have complaints regarding esthetics.

Dal Santo et al. evaluated the bite-force values and EMG activity of masseter muscles alone while recording masticatory force in 10 patients with a unilaterally fractured ZOC. They followed all patients for 4 weeks and 5 patients from the eighth to fifteenth week after surgery. Several kinds of treatments were involved. One patient received conservative treatment; another only had the fracture reduced with a Carroll-Girard approach is also relatively rapid and simple, and complications are few. Damage to branches of the facial

### Table III. Bite-force measurements (kgf) in the 6-month period

<table>
<thead>
<tr>
<th></th>
<th>1 wk</th>
<th>2 wk</th>
<th>3 wk</th>
<th>4 wk</th>
<th>2 mo</th>
<th>3 mo</th>
<th>4 mo</th>
<th>5 mo</th>
<th>6 mo</th>
<th>Control</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right molar</td>
<td>22.27 ± 5.55</td>
<td>23.11 ± 5.90</td>
<td>30.56 ± 4.06</td>
<td>31.14 ± 5.67</td>
<td>35.67 ± 4.39</td>
<td>40.04 ± 5.54</td>
<td>39.01 ± 7.95</td>
<td>37.16 ± 5.85</td>
<td>38.90 ± 5.95</td>
<td>54.26 ± 5.46</td>
<td>*</td>
</tr>
<tr>
<td>Left molar</td>
<td>21.63 ± 2.41</td>
<td>27.92 ± 1.63</td>
<td>31.81 ± 6.53</td>
<td>30.71 ± 5.24</td>
<td>32.51 ± 5.17</td>
<td>37.96 ± 7.27</td>
<td>37.72 ± 8.65</td>
<td>43.92 ± 9.58</td>
<td>42.58 ± 8.45</td>
<td>59.17 ± 5.9</td>
<td>*</td>
</tr>
<tr>
<td>Incisor</td>
<td>8.14 ± 1.77</td>
<td>10.14 ± 3.15</td>
<td>11.42 ± 2.38</td>
<td>10.17 ± 2.12</td>
<td>11.37 ± 2.15</td>
<td>13.05 ± 3.78</td>
<td>12.56 ± 3.32</td>
<td>11.49 ± 2.34</td>
<td>14.63 ± 4.34</td>
<td>15.32 ± 1.7</td>
<td>*</td>
</tr>
</tbody>
</table>

**Sig.** Significance.

*Significant.

### Table IV. Mandibular mobility measurements in the 6-month period

<table>
<thead>
<tr>
<th></th>
<th>1 wk</th>
<th>2 wk</th>
<th>3 wk</th>
<th>4 wk</th>
<th>2 mo</th>
<th>3 mo</th>
<th>4 mo</th>
<th>5 mo</th>
<th>6 mo</th>
<th>Control</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth opening</td>
<td>40.19 ± 4.33</td>
<td>44.91 ± 3.44</td>
<td>46.44 ± 4.89</td>
<td>48.22 ± 3.82</td>
<td>48.43 ± 3.23</td>
<td>48.36 ± 1.82</td>
<td>49.88 ± 3.01</td>
<td>49.88 ± 2.32</td>
<td>51.4 ± 1.77</td>
<td>48.85 ± 2.5</td>
<td>*</td>
</tr>
<tr>
<td>Right laterality</td>
<td>8.65 ± 0.84</td>
<td>9.69 ± 0.87</td>
<td>9.29 ± 1.12</td>
<td>9.18 ± 1.08</td>
<td>8.47 ± 1.06</td>
<td>9.02 ± 0.75</td>
<td>8.80 ± 0.94</td>
<td>9.29 ± 1.29</td>
<td>9.46 ± 1.35</td>
<td>8.9 ± 0.55</td>
<td>NS</td>
</tr>
<tr>
<td>Left laterality</td>
<td>8.26 ± 0.73</td>
<td>8.30 ± 0.90</td>
<td>8.34 ± 0.85</td>
<td>8.60 ± 1.26</td>
<td>8.87 ± 1.01</td>
<td>9.18 ± 1.36</td>
<td>8.23 ± 0.90</td>
<td>9.72 ± 1.18</td>
<td>9.14 ± 1.36</td>
<td>8.32 ± 0.52</td>
<td>NS</td>
</tr>
<tr>
<td>Protrusion</td>
<td>3.59 ± 0.76</td>
<td>4.19 ± 0.64</td>
<td>4.53 ± 0.86</td>
<td>4.90 ± 0.64</td>
<td>4.81 ± 0.57</td>
<td>5.83 ± 2.01</td>
<td>4.86 ± 0.75</td>
<td>5.63 ± 0.79</td>
<td>5.00 ± 0.9</td>
<td>4.71 ± 0.6</td>
<td>NS</td>
</tr>
</tbody>
</table>

**Sig.** Significance; NS, not significant.

*Significant.
screw; the other 8 patients were treated with surgery and RIF of ≥2 points of the ZOC, preferably the frontal zygomatic region and zygomaticomaxillary buttress. The synthesis methods used were positional plates measuring 1.5 and 2.0 mm and compression plates. A control group was also arranged.

The study results achieved by dal Santo et al. showed that bite force and EMG activity were slightly reduced in the fracture group compared with the control group and that there was an increase in bite force and EMG for patients in the fracture group with a fractured ZOC throughout the evaluated postoperative period. Only one of the patients achieved values equal to those of the control group during the 14-week postoperative period. Regarding bite force, the control group presented a mean value of 49.5 kgf for the right side and 48.9 kgf for the left side.

The present study results regarding bite force are in agreement with those of dal Santo et al.; Tate et al.; and Gerlach and Schwarz, in which bite force was reduced immediately after surgery and then increased throughout the evaluation period. In the present study, however, there was a different trend in the EMG activity compared with the study by dal Santo et al. In the present study, EMG activity increased and later declined, which may have occurred because of the technique used or the particularities of each sample.

Tate et al. evaluated bite-force values bilaterally in the region of the molars and incisors in 35 patients with mandibular angle fractures. All fractures were treated with surgery and RIF. The authors showed that bite-force values increased during the evaluation period but were reduced compared with the control group. The authors also reported a statistically significant difference when the 6-week period was compared with the later periods, but bite-force values remained lower than those of the control group.

Gerlach and Schwarz performed a bite force study in the region of the molars, canines, and incisors in 22 patients with mandible fractures treated with the Champy technique. Those authors showed that the maximum bite force achieved by the group treated in the first week was 31% that of the control group and that the force reached 58% in the sixth and final week of the evaluation. A similar result was observed in the present study of ZOC fractures, in which the mean bite force in the first molar region was 38.5% that of the control group in the eighth week (the second month).

In the present study, 6 months after surgery the bite-force values in the region of first molars were close to 70% of the control group values, and in the region of the central incisors the bite-force values were very close (95.4%) to those of the control group.

Physical and physiologic effects of trauma may affect the masticatory muscles, either directly or by releasing inflammatory mediators. Pain is a factor that clearly limits muscular activity, in addition to the neuromuscular protection system.

Based on the EMG data during rest for the group with a fractured ZOC, it was verified that the masseter muscles presented a 30% increase in EMG activity compared with the control for the right masseter, and a 2.1% increase for the left. As for the temporal muscles, the results showed a 31.7% higher activation for the right temporal muscle and 38.3% for the left. The EMG activity in the temporal muscles was high, a pattern that is characteristic of individuals with stomatognathic system dysfunctions.

Despite the small sample, it was possible in the present study to treat patients with the same surgical technique regarding surgical approach (intraoral) and RIF (1 plate in the region of the zygomaticomaxillary buttress), with a total of 9 follow-up appointments during the 6 months after surgery. In these conditions, there were no dietary restrictions as a result of the trauma, and the patients recovered normal function regarding bite force and EMG activity after the second month. There was no effect on mandibular mobility, apart from maximum mouth opening, which returned to the normal level during the first month after surgery.

We conclude that bite force values increased and EMG activity values decreased until the second month after surgery, after which the normal pattern was reestablished. As for mandibular mobility, changes were observed only for the limitation of mouth opening until the first postoperative month. Further studies with larger samples and standardization of the treatment used should be performed to confirm this pattern of recovery.

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