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ORIGINAL ARTICLE

# Prospective Analysis of the Swallowing Reflex After Sagittal Split Osteotomy: Comparison with Normal Volunteers

Aysenur Genc[1] · Sabri Cemil Isler[1] · Cengizhan Keskin[1] · Ali Emre Oge[2] · Zeliha Matur[3]

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**Abstract**

The aim of this study was electromyographic description of changes in swallowing before and after bilateral sagittal split ramus osteotomy. In this prospective study, twenty-eight patients were divided into 3 groups according to the occlusion pattern: Group I (Angle Class III), Group II (Angle Class II), and Control (Class I). Serial cone-beam computed tomography analyses and electromyographic data were collected preoperatively, 1st and 6th months after setback surgery in Group I, and advancement surgery in Group II. Swallowing reflex with 3–20 ml water bolus were studied. Patients were further divided into two subgroups according to the magnitude of relapse. The mean setback of the mandible was $4.62 \pm 1.92$ mm in Group I, and the mean advancement was $4.19 \pm 2.00$ mm in Group II. Mandibular relapse rate was 17.40%. Oral preparation phase shortened after surgery in both study groups. Two subjects in Group II and one in Group I had piecemeal deglutition, and two of them became normal postoperatively. Most of the swallowing durations of the relapsed cases were longer than those of stabilized patients. Important clinical considerations are as follows: the oral preparation period becomes shorter after surgery; piecemeal deglutition may disappear after treatment; and individuals with a longer oral period and piecemeal deglutition may have increased tendency to skeletal relapse. This multidisciplinary study enhances our understanding of the adaptive response to the swallowing reflex after orthognathic surgery and provides novel insight into the association between the submental muscle activity and relapse in orthognathic patients.

**Keywords** Sagittal split osteotomy · Dentofacial deformity · Swallowing reflex · Electromyography · Deglutition · Deglutition disorders

## Introduction

Skeletal malocclusions can be managed with surgical manipulations of dentofacial apparatus. Bilateral sagittal split osteotomy (BSSO) is routinely used as an orthognathic surgical procedure to treat mandibular deformities. Mandibular surgical intervention improves the occlusion and skeletal position of the mandible and oropharyngeal complex [1]. There is a close inter-relationship between the soft tissue profile and skeletal structures. The sagittal, vertical, or transverse orientation of the mandible inevitably involves shortening or elongation of adjacent soft tissue structures. The repositioning of the mandible also affects the geniohyoid and genioglossus muscles, controlling the posture of the tongue and hyoid bone. Since muscle and nerve groups are responsible for the peripheral feedback mechanism of the reflex responses, orthognathic surgery might affect the brainstem's central motor program of reflexes.

Previous studies assessed the effects of mandibular surgery on masticatory function, stomatognathic function, sleep apnea, psychosocial status, and articulation [2–8]. No previous investigation had simultaneously evaluated whether mandibular surgery affects the swallowing reflexes. Our working hypothesis is that if the changes in mandible position affects mastication, respiratory function, and upper airway patency, it could also influence brainstem reflexes, so we postulated that swallowing reflex may be modified by peripheral changes induced by orthognathic surgery, due to

✉ Aysenur Genc
anuruzun@gmail.com

[1] Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Istanbul University, Istanbul, Turkey

[2] Department of Neurology, Istanbul Medical Faculty, Istanbul University, Istanbul, Turkey

[3] Department of Neurology, Faculty of Medicine, Istanbul Bilim University, Istanbul, Turkey

the altered relationship between muscle–nerve groups and the brainstem.

The current article focuses on surface electromyographic (sEMG) expression of the functional changes in swallowing before and after BSSO. Accordingly, we tested the hypothesis that BSSO would modulate the swallowing reflex.

## Materials and Methods

### Study Design

Three groups of patients participated in this prospective clinical study, which was approved by the "Institutional Ethical Board". A total of 28 subjects, aged 26.0 ± 4.1 years, were allocated into groups based on the occlusion pattern: Group I (Angle Class III malocclusion, 7 patients), Group II (Angle Class II malocclusion, 7 patients), and Control Group (Class I occlusion, 14 healthy subjects). All patients were diagnosed by clinical examination, cephalometric study, and cast mounting to demonstrate dentoskeletal dysmorphism and the need for BSSO. Patients who will have two-jaw orthognathic surgery and genioplasty, the presence of craniofacial anomalies, congenital malformations with associated growth disorders, maxillofacial trauma, or jaw bone defects, as well as dysfunction in the masticatory muscles and bilateral temporomandibular joints were excluded. Patients who had any disease of the central nervous system (CNS) and those taking drugs that can affect the CNS were also excluded. Testing occurred: (1) 1 to 2 days before orthognathic surgery (i.e., after presurgical orthodontic treatment), (2) 1 month after surgery (BSSO for setback of the mandible in Group I and advancement in Group II), and (3) postoperative at 6 months. All subjects signed an informed consent to participate voluntarily.

### Imaging Procedures and Assessment

All patients in the study groups had standardized pre- and postoperative "cone-beam computed tomography (CBCT)" scans. CBCT scans were performed with "Soredex Scanora 3D-X (by Soredex, Tuusla, Finland) CBCT" and maintained by 10 mA, 70 kVp, 180 mm × 160 mm FOV (Field of View). Every CBCT scan was taken with patients sitting in an upright position, breathing quietly, the tongue in a relaxed position, and aligning the clinical Frankfort horizontal plane parallel to the floor. Three-dimensional CBCT images were registered with cranial base superimposition of "Mimics® Research (v19.0.0.347; Materialise, Inc., Leuven, Belgium)", while the distances between anatomic landmarks and reference planes were measured, based on three-dimensional reconstructed images. Reference planes are in Fig. 1.

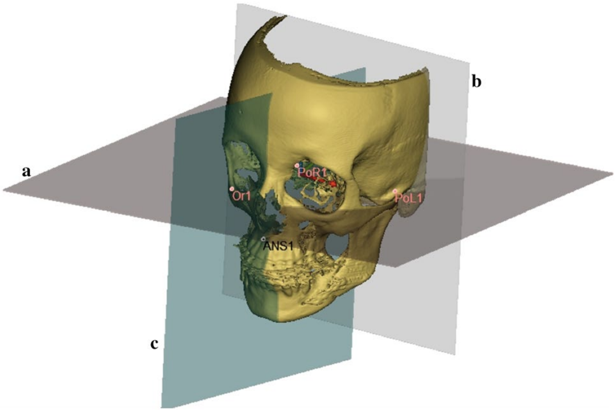

**Fig. 1** Reference planes. **a** Horizontal plane (*x*-axis): between left Porion (PoL), right Porion (PoR), and Orbitale. **b** Vertical line (*y*-axis): from PoL and PoR, perpendicular to *x*-axis. **c** Sagittal plane: perpendicular to *x*- and *y*-axis through ANS. *ANS* the tip of the bony anterior nasal spine in the median plane, *Orbitale* the most anterior, inferior point on the infraorbital rim, *Porion* the upper midpoint on the external auditory meatus

We measured surgical relapse as the change in horizontal distance from B to the *y*-axis in the sagittal plane. This is where B has the deepest midline in the outer contour of the anterior mandible; we calculated relapse rate by dividing postsurgical changes by surgical changes (T3 vs T2/T1 vs T2). Reference lines and angles are given in Fig. 2.

### Swallowing Reflex Studies

Each subject sat on an examination chair and was requested to hold her/his head in a natural upright position. In all groups, the swallowing reflex was studied with 3, 10, 15, and 20 ml of water bolus (T1, preoperatively). Electrophysiological tests were repeated postoperatively 1st (T2) and 6th (T3) months in Groups I and II. Five repetitions for each pattern, 20 recording per visit, 1120 in total, were performed to ascertain stability of the sEMG recordings.

This study used the sEMG method of Ertekin et al. [9]. When swallowing, EMG recordings of mylohyoid-geniohyoid-anterior digastric muscle complex activity were obtained from the two surface electrodes attached on two sides of the midline beneath the chin (referred to as the submental EMG (SM-EMG)). A custom-made mechanical sensor, kindly provided by Professor Aydoğdu from Ege University, consisting of a piezoelectric wafer, was placed between the cricoid and thyroid cartilages on the midline (Fig. 3a). We defined labeled electrophysiological parameters as follows: (1) Two deflections in the laryngeal sensor signal recordings were denoted as 0 and 2. The "0-2 interval" was the time variable that indicated the pharyngeal phase of swallowing, including the laryngeal upward movement and relocation time. (2) As contraction of the

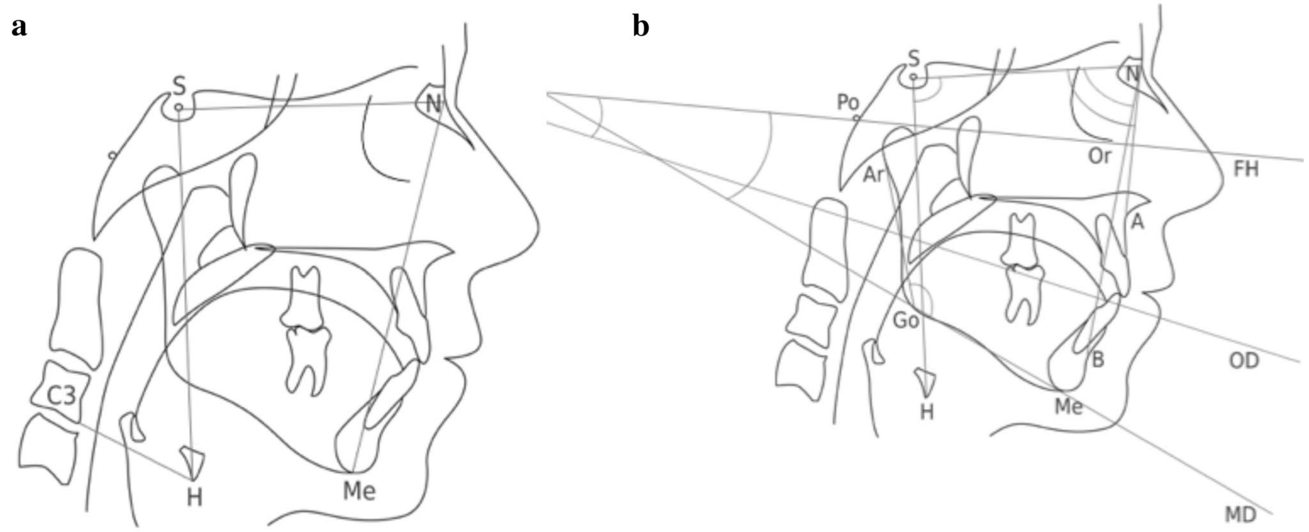

**Fig. 2** **a** Reference lines: *(ANB)* angle formed by A point, Nasion, and B point, *(C3-H)* distance between the hyoid bone and the third cervical vertebra, *(N-Me)* distance between Nasion and Menton, *(SH)* distance between Sella and anterior point of the hyoid bone, *(SN)* distance between Sella and Nasion. **b** Reference angles: *(SNA)* angle formed by Sella, Nasion, and A point, *(SNB)* angle between Sella, Nasion, and B point, *HSN* angle between Hyoid, Sella, and Nasion, *(FH/MD)* angle between Frankfort horizontal and mandibular plane, *(FH/OD)* angle between Frankfort horizontal and occlusal plane, *Ar–Go–Me* gonial angle. *A point* the deepest midline point of the anterior maxilla, *Articulare* the intersection of the posterior margin of the ascending ramus and the outer margin of the cranial base, *B point* the deepest midline point of the anterior mandibular contour, *C3* the most inferior, anterior point on the third cervical vertebra, *H point* the most superior, anterior point of the hyoid body, *Sella* the midpoint of the hypophyseal fossa, *Gonion* the intersection of the lines tangential to the posterior margin of the ascending ramus and the mandibular base, *Menton* the most caudal point in the outline of the symphysis, *Nasion* the most anterior point of the nasofrontal suture, *frankfort horizontal* *x*-axis, *mandibular plane* through the left gonion, right gonion, menton, *occlusal plan*e through left and right lower first molar and incisor

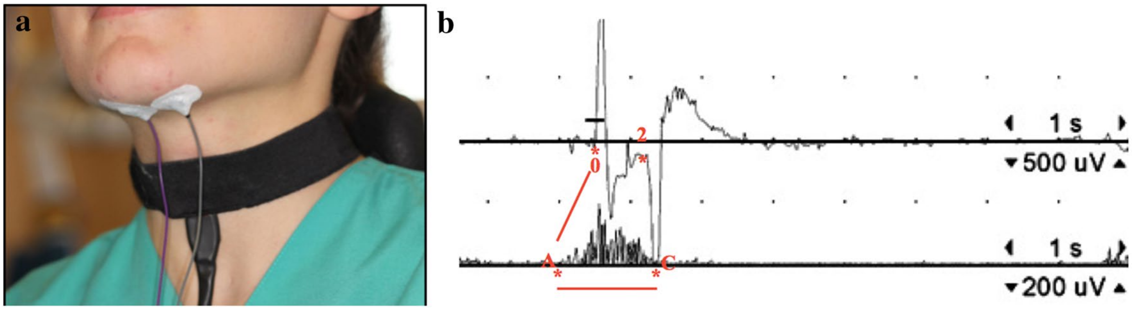

**Fig. 3** **a** Swallowing reflex: placement of submental SM-EMG electrodes and piezoelectric sensor. **b** Laryngeal sensor signal (top) and submental muscle; EMG activities (bottom) when swallowing water. (A–0 interval), triggering of swallowing; (0-2 interval), laryngeal upward location; (A–C interval), submental muscle activity duration

submental muscles, functioning as laryngeal elevators, continues until the end of the oropharyngeal swallowing process, the SM-EMG was assumed to ensure information about the onset and duration of the oropharyngeal phase of swallowing, in the period called as the “A-C interval”. (3) We referred to the third parameter as the “A-0 interval,” which was the time period between the onset of SM-EMG (A) and upward deflection (0) of the laryngeal sensor. This interval demonstrated the triggering of swallowing reflex (Fig. 3b).

## Surgical Procedure

Patients underwent single jaw orthognathic surgery with BSSO according to the Obwegeser/Dal-Pont method in the Oral and Maxillofacial Surgery department. All subjects received preoperative and post-operative orthodontic treatment. In Group I, seven patients with prognathic mandible underwent setback BSSO. Seven patients with retrognathic mandible were treated with advancement BSSO in Group II. The bone fragments were fixed using titanium miniplates and screws (KLS Martin, Tuttlingen, Germany). Intermaxillary fixation with elastics was maintained for 15 days postoperatively.

### Statistical Analysis

All analyses were performed with IBM SPSS Statistics V22.0 (Armonk, NY, USA). The Kolmogorov–Smirnov test was used to check if a certain variable was normally distributed. Since some data were not normally distributed, and the number of patients in the groups was small, comparisons between groups were made by non-parametric tests; the Kruskal–Wallis test was used for multiple group comparisons and the Mann–Whitney *U* test was used for pairwise group comparisons. The changes of electrophysiological parameters in terms of study times T1, T2, and T3 were compared with the Friedman test. If there was a significant difference, pairwise comparisons were made by the Wilcoxon-signed rank test, and the Bonferroni correction was used as a *post hoc* test. The skeletal changes at T1, T2, and T3 were compared with the paired *t* test (T1 vs T2, T2 vs T3, T1 vs T3). The relapse rate was calculated from the horizontal distance from B to the *y*-axis (T3 vs T2/T1 vs T2 × 100%). Both the stable and relapse groups were based on the magnitude of surgical relapse. The cut point was set according to the mean of relapse in these 14 patients. The electrophysiological parameters were compared between stable and relapse groups with the Mann–Whitney *U* test. The significance level was $p < 0.05$.

## Results

### Computed Tomography Analysis

Measurements of surgical and postsurgical changes between the three different time intervals T1–T2, T2–T3, and T1–T3 are shown in Table 1. Considering sagittal skeletal changes, the mandible showed a mean setback of 4.62 ± 1.92 mm in Group I, with a mean advancement of 4.19 ± 2.00 in Group II. The ANB angle increased 4.04° in Group I and decreased 1.74° from T1 to T3 ($p < 0.05$). In patients with prognathic mandible, the position of the hyoid bone was significantly displaced backwards after surgery, then showed further anterior movement, and gradually returned to its original position on 6 months follow-up. The distance between the hyoid bone and the third cervical vertebra significantly increased in Group II from T2 to T3.

As vertical skeletal changes, the anterior facial height decreased by 2.15 mm; the posterior facial height increased by 2.45°, the occlusal plane and mandibular plane were accompanied with a significant mean increase of 1.84° and 2.45°, respectively, from T1 to T3 in Group I. In patients with mandibular advancement, significant increase of the anterior facial height was seen from T1 to T3. The gonial angle significantly increased in Group I and II by 1.52° and 9°, respectively, from T1 to T3. A significant increase was seen in Group II in vertical movement of the hyoid bone (SH), between T1–T2 and T1–T3.

The horizontal displacement (mm) between the "B" point and *y*-axis across groups was not significant at T2–T1, T2–T3, T1–T3. There was no statistically significant difference between groups in terms of the magnitude of the surgical movement. The average sagittal relapse rate was 17.40%. Patients were further divided into two subgroups according to the magnitude of relapse, which ranged from 15.87 to 3.28% in the stable group. Four patients were involved in the relapse group if the rate was between 25.47 and 38.37%. Mandibular skeletal relapse developed in three patients in Group I and one in Group II. The Fisher exact test was performed to analyze the significance of the association between the relapse and direction of surgical movement. There was no difference in stability between both groups.

### Swallowing Reflex

Swallowing reflex findings are summarized in Table 2. There was no statistically significant difference between the three groups at baseline. A-0 interval was statistically shorter with 10 ml of water in Group I at T2 ($p = 0.021$). The SM-EMG period was statistically different with 20 ml of water between Groups I and II during the 1st postoperative month ($p = 0.045$). Other measurements at T2, T3 showed no significant difference.

The postoperative measurements at the 1st (T2) and 6th month (T3) showed no significant difference from T1 in either group (Table 2). On the other hand, some remarkable changes were observed as follows:

1- One month after surgery (T2), the oral period (A-0 interval) shortened with 3, 10, 15, and 20 ml of water in Group I, with 10 and 15 ml of water in Group II, but the differences were not statistically significant. The A-0 period of the treatment groups decreased postoperatively, on average much more in Group I, and did not return to preoperative levels in the 6th month after the operation.
2- The pharyngeal phase of swallowing (0-2 interval) was prolonged with 3, 10, and 15 ml of water in Group II during the postoperative follow-up. The 0-2 interval with 20 ml of water at T2 was slightly shorter than preoperative levels in both groups.
3- SM-EMG period which was performed by using 15 to 20 ml of water clearly decreased in Group I.

**Table 1** Serial tomographic measurements and analysis of the study groups. (*mean–standard deviation*)

| | Group | T1 | T2 | T3 | T2–T1 | T3–T2 | T3–T1 |
|---|---|---|---|---|---|---|---|
| ANB (°) | I | −0.82–2.30 | 3.26–1.23 | 3.22–1.31 | 4.08–1.86* | −0.04–0.40 | 4.04–1.78* |
| | II | 5.28–3.44 | 3.62–0.87 | 3.53–0.87 | −1.65*–2.84 | −0.09–0.40 | −1.74*–2.86 |
| ANS−*x* (mm) | I | 21.43–3.48 | 21.60–3.54 | 21.91–3.61 | 0.18–0.63 | 0.31–0.41 | 0.48–1.00 |
| | II | 25.54–5.30 | 25.75–6.25 | 26.02–6.33 | 0.21–1.16 | 0.27–0.48 | 0.48–1.27 |
| ANS−*y* (mm) | I | 89.29–4.11 | 90.95–3.27 | 89.88–3.15 | 1.66–2.52 | −1.07–1.08 | 0.59–2.10 |
| | II | 93.15–12.87 | 92.75–12.56 | 92.45–11.89 | −0.40–1.46 | −0.31–0.94 | −0.71–1.38 |
| Ar–Go–Me (°) | I | 123.43–6.77 | 123.88–7.35 | 124.94–4.35 | 0.45–5.14 | 1.06–3.31 | 1.52*–4.89 |
| | II | 113.41–14.06 | 121.24–6.00 | 122.41–7.58 | 7.83*–25.39 | 1.18–2.52 | 9.00*–24.76 |
| A*x* (mm) | I | 26.05–4.22 | 25.85–4.40 | 26.3–±3.84 | −0.20–1.04 | 0.53–1.23 | 0.33–1.55 |
| | II | 27.13–2.66 | 27.48–2.75 | 27.28–2.79 | 0.35–0.36 | −0.20–0.52 | 0.15–0.75 |
| *y* (mm) | I | 85.10–3.96 | 84.82–4.35 | 85.03–4.09 | −0.28–0.892 | 0.21–0.74 | −0.07–0.78 |
| | II | 87.80–12.44 | 88.32–12.28 | 86.88–12.00 | 0.52–1.89 | −1.44–1.16 | −0.92–1.82 |
| B*x*(mm) | I | 67.23–8.93 | 66.90–7.50 | 67.82–7.30 | −0.33–2.68 | 0.92–1.15 | 0.59–2.25 |
| | II | 70.02–5.52 | 69.96–7.41 | 70.23–6.88 | −0.06–2.56 | 0.27–1.20 | 0.21–2.69 |
| B*y* (mm) | I | 86.48–6.09 | 81.87–6.44 | 82.67–6.47 | −4.62*–1.92 | 0.81–0.57 | −3.81*–1.90 |
| | II | 77.17–16.75 | 81.36–15.78 | 80.63–16.20 | 4.19*–2.00 | −0.73–0.54 | 3.46*–1.64 |
| C3-H (mm) | I | 37.50–5.46 | 35.36–7.35 | 37.34–5.48 | −2.14*–2.73 | 1.99*–2.94 | −0.15–1.21 |
| | II | 35.15–6.04 | 41.06–3.97 | 38.89–6.00 | 5.91*–4.37 | −0.74*–4.16 | 3.75*–5.87 |
| FH/MD (°) | I | 27.99–5.97 | 30.96–5.73 | 30.44–5.45 | 2.97*–2.16 | −0.53–0.94 | 2.45*–2.86 |
| | II | 29.52–5.33 | 29.47–7.60 | 29.25–7.37 | −0.06–3.73 | −0.22–0.31 | −0.27–3.51 |
| FH/OD (°) | I | 12.10–4.92 | 11.30–4.80 | 13.14–5.62 | −0.80–3.37 | 1.84*–1.58 | 1.03–4.14 |
| | II | 10.67–2.72 | 11.30–0.84 | 10.93–0.80 | 0.63*–2.08 | −0.37*–0.55 | 0.26–2.58 |
| HSN (°) | I | 96.34–4.48 | 98.21–4.81 | 97.05–3.36 | 1.87–2.82 | −1.16–3.64 | 0.72–3.43 |
| | II | 93.80–5.08 | 95.41–6.48 | 93.87–5.64 | 1.61*–4.33 | −1.54*–3.01 | 0.06–4.88 |
| L1−*x* (mm) | I | 49.60–7.26 | 49.55–8.08 | 50.32–7.06 | −0.06–0.95 | 0.78–1.66 | 0.72–1.35 |
| | II | 52.87–6.15 | 53.33–7.61 | 54.18–8.33 | 0.46–1.90 | 0.86–1.03 | 1.32*–2.57 |
| L1−*y* (mm) | I | 91.56–5.22 | 89.53–5.96 | 88.37–6.41 | −2.03*–3.71 | −1.17–1.08 | −3.20*–3.17 |
| | II | 85.26–14.45 | 88.83–13.34 | 87.77–13.40 | 3.57*–2.91 | −1.06–1.26 | 2.51*–3.28 |
| N–Me (mm) | I | 118.56–10.2 | 117.77–9.47 | 116.38–8.08 | −0.79–1.12 | −1.39–2.42 | −2.18*–3.19 |
| | II | 116.42–12.64 | 117.36–11.14 | 118.57–11.03 | 0.94–2.95 | 1.22–1.20 | 2.15*–3.05 |
| SH (mm) | I | 106.87–7.59 | 104.51–5.28 | 105.41–5.81 | −2.36–2.85 | 0.90–2.16 | −1.46–2.75 |
| | II | 105.34–13.59 | 108.33–15.14 | 108.74–15.94 | 2.99*–3.63 | 0.41–2.09 | 3.40*–3.13 |
| SN (mm) | I | 65.08–3.11 | 65.08–3.26 | 65.20–3.05 | 0.00–0.42 | 0.12–0.64 | 0.13–0.29 |
| | II | 63.79–7.91 | 63.58–9.02 | 63.46–8.74 | −0.21–1.57 | −0.12–1.99 | −0.32–2.49 |
| SNA (°) | I | 78.34–3.40 | 78.77–3.11 | 79.08–3.34 | 0.43–0.64 | 0.30–0.51 | 0.73–0.28 |
| | II | 82.11–1.94 | 81.70–1.25 | 88.02–3.65 | −0.42–2.29 | −0.33–3.03 | −0.09–3.45 |
| SNB (°) | I | 79.18–2.49 | 77.43–2.91 | 77.64–2.40 | −1.75*–2.22 | 0.21–0.76 | −1.54*–1.88 |
| | II | 76.75–2.64 | 78.83–1.81 | 78.91–2.12 | 2.08*–1.87 | 0.08–1.02 | 2.16*–1.28 |
| U1*x* (mm) | I | 50.84–5.64 | 50.43–5.41 | 50.83–5.51 | −0.41–0.99 | 0.40–1.64 | −0.01–1.25 |
| | II | 54.97–5.99 | 55.17–7.28 | 55.88–8.29 | 0.19–1.50 | 0.72–1.29 | 0.91–2.76 |
| U1*y* (mm) | I | 91.90–3.84 | 92.85–3.53 | 92.65–4.07 | 0.95–1.56 | −0.20–1.45 | 0.76–1.53 |
| | II | 91.99–12.04 | 92.67–12.65 | 91.70–11.86 | 0.67–1.02 | −0.97–1.16 | −0.29–0.74 |

*ANS* the tip of bony anterior nasal spine in the median plane, *ANS-X* horizontal distance from ANS to *y*-axis, *ANS-Y* vertical distance from ANS to *x*-axis, *Ar–Go–Me* angle formed by Articulare, Gonion, and Menton (gonial angle), *A–X* horizontal distance from A to *y*-axis, *A-Y* vertical distance from A to *x*-axis, *B-X* horizontal distance from B to *y*-axis, *B-Y* vertical distance from B to *x*-axis, *L1-X* horizontal distance from lower incisor to *y*-axis, *L1-Y* vertical distance from lower incisor to *x*-axis, *SD* standard deviation, *T1* before surgery, *T2* 1 month after surgery, *T3* 6 month after surgery, *U1-X* horizontal distance from upper incisor to *y*-axis, *U1-Y* vertical distance from upper incisor to *x*-axis. (C3-H), (N–Me), (SH), (SN), (SNA), (SNB), (HSN), (FH/MD), (FH/OD), (Ar–Go–Me) described in Fig. 1

*$p < 0.05$

**Table 2** Swallowing reflex findings [mean (standard deviation)] at baseline (T1), postoperative at 1st month (T2), and at 6th month (T3)

| Group | T1 | | | T2 | | T3 | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | Control | 1 | 2 | 1 | 2 |
| A-0 | | | | | | | |
| 3 ml | 354.3 (80.2) | 350 (90.4) | 341.4 (94.5) | 280 (70) | 322.9 (50.9) | 268.6 (86.1) | 282.9 (49.2) |
| 10 ml | 338.5 (88.2) | 348.5 (63.8) | 361.4 (97.1) | 233.3 (36.6)* | 298.5 (57.8)* | 325.7 (89.7) | 261.4 (86.8) |
| 15 ml | 347.1 (84) | 334.2 (52.2) | 355 (97.2) | 243.3 (35.5) | 270 (64) | 311.4 (49.1) | 301.4 (53.6) |
| 20 ml | 358.5 (76.4) | 304.2 (72) | 325 (68.4) | 276.6 (61.5) | 300 (56.8) | 288.5 (80.7) | 291.4 (92.2) |
| 0-2 | | | | | | | |
| 3 ml | 627.1 (171.2) | 641.4 (105.4) | 657.8 (146.2) | 615.0 (71.4) | 738.5 (160.3) | 680 (137.4) | 725.7 (167.7) |
| 10 ml | 692.8 (141.3) | 657 (103.5) | 679 (148.8) | 655 (102.1) | 758.5 (162.1) | 607.1 (159.2) | 744.2 (173.9) |
| 15 ml | 680 (149.3) | 637.1 (75.8) | 711 (134.2) | 615 (146.1) | 722.8 (140.3) | 684.2 (187.7) | 675.7 (169.6) |
| 20 ml | 707.1 (123.1) | 738.5 (194.7) | 736.4 (115.1) | 626.6 (110.5) | 611.4 (176.2) | 667.1 (86.5) | 729 (141.3) |
| A-C | | | | | | | |
| 3 ml | 1041.4 (185.1) | 974.2 (195.1) | 981.4 (198.2) | 950 (168) | 1062.8 (203.3) | 1022.8 (300.4) | 1015.7 (189.9) |
| 10 ml | 1214.2 (434.1) | 1005.7 (237.6) | 997.8 (173.3) | 976.6 (208.4) | 1120 (267.5) | 1017.1 (252.2) | 1278.5 (432.6) |
| 15 ml | 1201.4 (393.1) | 994.2 (200.3) | 1095.7 (178.5) | 1033.3 (206.6) | 1290 (632.9) | 1138.5 (276.4) | 1402.8 (538.9) |
| 20 ml | 1250 (567.3) | 1274.2 (822.3) | 1157.1 (305.7) | 1066.6 (126.2)$^{\#}$ | 1391.4 (369.5)$^{\#}$ | 1084.2 (277.3) | 1387.1 (764.8) |

*, $^{\#}$ $p<0.05$

With regard to postoperative stability, the SM-EMG period with 20 ml of water was statistically shorter in the stable group at T1 and T3 ($p=0.019$, $p=0.029$, respectively) (Fig. 4). The A-C interval was similar in the relapse and stable groups at T2.

A-0 and 0-2 intervals of swallowing in relapsed cases were longer than those of the stabilized patients. There were no significant differences in total swallowing time between the relapse and stable groups.

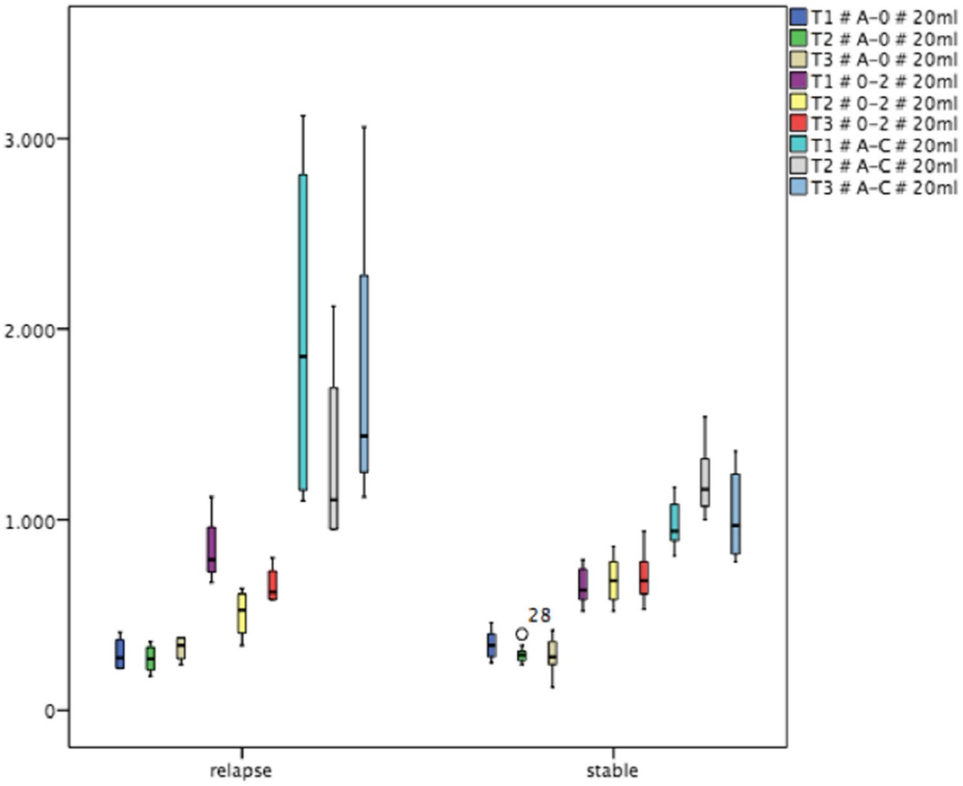

**Fig. 4** Swallowing periods with 20 ml in the relapse and stable groups

Two normal subjects could not swallow the material all at once, so the bolus volume was divided into two aliquots and successively swallowed with increased SM-EMG activity. Two patients in Group II and one in Group I had this piecemeal deglutition during swallowing of 10–20 ml of water, and two of them normalized after surgery.

## Discussion

The present study investigates the electrophysiological swallowing reflex in patients with skeletal malocclusion both before and after surgery. Serial CBCT analyses and sEMG data were collected to clarify adaptation of the swallowing reflex and the effect of submental muscle activity on mandible skeletal stability. Physiological characteristics of swallowing reflex were previously clarified in several studies [10–12].

Swallowing pattern involves a stereotyped sequential motor activity of several muscles of the mouth, pharynx, larynx, and esophagus. It is commonly subdivided into 3 phases: (1) initial oral phase, triggered by the entrance of the in the oral cavity, bolus propulsion to the pharyngeal cavity; (2) pharyngeal phase, laryngeal elevation and closure, contraction of the suprahyoid/submental muscles; and (3) esophageal phase, the propulsive tongue action, and the opening of the upper esophageal sphincter for bolus transportation into the esophagus [13]. Our study described the hypothesis that the swallowing reflex can be influenced by peripheral alterations from the orthognathic surgery (as the mandible anchors the tongue, hyoid bone, and muscles involved in swallowing).

Graphically, a typical single water swallow can be observed on the sEMG recordings as upward and downward laryngeal deflections and integrated SM-EMG activity. The A-0 interval is the period between SM-EMG onset and the appearance of the first deflection of the laryngeal sensor. This interval reflects sensory input transmitted to the brainstem, which is related to the swallowing trigger [9]. We observed that, depending on the oral preparation period (A-0 interval), the corticobulbar excitability of swallowing was significantly altered by mandibular surgery. In accord with Namaki's videofluoroscopic study, the change of mandible position reduced the oral preparation period [13]. Gaukroger reported that a possible cause of the dysphagia might be a change of the anatomical dimensions of the hyoid region, following the mandibular setback, with posterior displacement of the suprahyoid muscles and the resultant shortening of their resting lengths [14]. In the present study, although the position of the hyoid bone was significantly displaced backwards after surgery and gradually returned to its original anterior position on 6 months follow-up in Class III patients, it moved anteriorly and inferiorly in Class II patients. Considering the study which showed further anterior and inferior movement in the following 11 years after mandibular setback, it can be said that a physiological adaptation occurs to preserve respiratory tract [1]. The authors' opinion is that the reduction of oral cavity volume, position of the hyoid bone, and anatomic modification of the suprahyoid muscles after surgery may cause a shortening of the oral preparation period. This suggests a possible clinically relevant adaptation of the swallowing function after BSSO, due to the surgical trauma that creates local neuromuscular misbalance. Each individual's reflex is under neuromuscular central control, which is itself adaptive, and thereby able to be modulated if the peripheral swallow environment is altered.

Surgically positioning the mandible tends to lengthen/shorten the suprahyoid muscles, particularly the anterior belly of the digastric, the mylohyoid, and the geniohyoid. It was suggested that suprahyoid musculature plays an important role in skeletal relapse [15, 16]. In our study, one of the most relevant data was obtained by sEMG. SM-EMG activity can be recorded by using an electrode pair taped under the chin, over the mylohyoid-geniohyoid-anterior digastric muscle complex [9]. The extended SM-EMG duration shows the longer relocation time of the larynx and the longer-lasting pulling effect of the submental muscles. In this study, the extent of relapse in patients who had a statistically longer SM-EMG period was higher. Overall, SM-EMG activity at baseline and the relapse rate showed a strong association. This could indicate that individualized swallowing retraining techniques may be helpful in increasing oral control of the bolus, tongue–palate contact, and a reduced risk of relapse. Furthermore, surgical overcorrection, rigid fixation, suprahyoid myotomy, botulinum toxin applications, and orthodontic retention techniques may be indicated to control relapse tendencies in BSSO [3, 16].

The authors presented a detailed analysis of swallowing before and after BSSO with the sEMG method described previously [17, 18]. Our study design was based on how most cited investigators concluded that EMG examinations have acceptable reliability to assess qualitative and quantitative dynamics. Moreover, sEMG provides information on the timing of selected muscle contraction patterns while swallowing, maximum biting, or blinking. It is reliable, noninvasive, time-saving, inexpensive, and as stated, can easily be learned by clinicians.

This multidisciplinary study enhances our understanding of the adaptive response of the swallowing reflexes with orthognathic surgery. However, the strength of our findings is somewhat tenuous because of the small sample size and the short duration of follow-up. Despite these limitations, to the best of the authors' knowledge, this is the only large, prospectively controlled clinical study attempting to assess the swallowing reflexes and the association between the submental muscle activity and relapse in orthognathic patients.

Based on the results of this study, following features ought to be contemplated for the patients undergoing BSSO: (1) The oral preparation period for swallowing becomes shorter after surgery; (2) piecemeal deglutition may disappear after treatment; and (3) individuals with longer oral period of swallowing and piecemeal deglutition may tend to develop skeletal relapse.

These results signify the necessity of the following: (1) systematized recording of swallowing reflexes, not only before orthognathic surgery but also during postoperative follow-up; (2) pronouncement of information on the increased relapse tendency for patients with a longer oral period of swallowing; (3) modification of surgical designs for overcorrection in those patients; and (4) proposal of swallowing therapy as part of their postoperative rehabilitation.

In conclusion, our results support the hypothesis that BSSO modulates the swallowing function. This modulation may clinically emerge as shortening of the oral period of swallowing and improvement in piecemeal deglutition after surgery. Additionally, our results suggest that, the presence of longer oral period of swallowing and piecemeal deglutition may indicate the tendency to skeletal relapse.

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## Compliance with Ethical Standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical Approval** The study conforms to the provisions of the Declaration of Helsinki (as revised in Tokyo 2004) and had been approved by the Institutional Review Board for Human Studies of the Dentistry Faculty of the Istanbul University, Turkey (Study 2015/69).

**Informed Consent** Written informed consent was obtained from each participant.

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**Aysenur Genc** PhD, DDS

**Sabri Cemil Isler** PhD, DDS

**Cengizhan Keskin** PhD, DDS

**Ali Emre Oge** MD

**Zeliha Matur** MD