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Impact of orthognathic surgery on the body posture

M. Paya-Argoud[a,1], C. Tardieu[a,b], F. Cheynet[c], A. Raskin[a,b], L. Borel[d,*]

[a] Aix Marseille Univ, CNRS, EFS, ADES, Faculté de Médecine, Bâtiment A, Boulevard Pierre Dramard, 13344, Marseille, France
[b] Assistance Publique Hopitaux de Marseille, pôle d'Odontologie, Hôpital de la Timone, 264 rue Saint Pierre, 13005, Marseille, France
[c] Assistance Publique Hopitaux de Marseille, service de Chirurgie Maxillo-faciale, Hopital de la Conception, 147 Boulevard Baille, 13005, Marseille, France
[d] Aix Marseille Univ, CNRS, LNSC, Marseille, France

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ABSTRACT

Background: Postural control is classically described as being based on the visual, vestibular, and proprioceptive musculo-articular sensory systems. The influence of mandibular proprioception on postural stabilization remains controversial. Most previous studies analyzed how postural stability is influenced by partial changes in mandibular proprioception (dental occlusion and jaw position).

Research Question: In the present experiment, we asked whether drastic mandibular changes, resulting from orthognathic surgery (including dental, joint and muscular efferents), modify postural control.

Methods: The analyzes were performed in 22 patients tested before, and 2.5 months, after orthognathic surgery for treatment of dysmorphic jaws. Experiments were performed under 4 experimental conditions: 2 visual conditions: Eyes Open (EO) and Eyes Closed (EC), and 2 occlusal conditions: Occlusion (OC: mandible positioned by the contact of the teeth), and Rest Position (RP: mandible positioned by the muscles without tooth contact). The analyses focused on head orientation in the frontal plane and on postural stabilization in a static task, consisting of standing upright.

Results: The results show that, 2.5 months after orthognathic surgery, head orientation in the frontal plane was improved, since patient's external intercanthal lines became closer to the true horizontal line when they were tested EC and in OC condition. Postural responses, based on the wavelet transformation data, highlight an improvement in maintaining an upright stance for all the tested sensory conditions. However, such improvement was greater in the EC and RP conditions.

Significance: These results show, for the first time, that after drastic mandibular changes, the weight of proprioceptive cues linked to the mandibular system may be so enhanced that it may constitute a new reference frame to orient the head in space, in darkness, and improve static postural stabilization, even in the presence of visual cues.

1. Introduction

Postural control is usually described as being based on information from the vestibular, visual, and proprioceptive systems [1–3]. In the past few decades, the specific role of the cranio-mandibular system has been highlighted by numerous studies, most of them involving dental proprioception. Nevertheless, mandibular position is controlled by three types of proprioception: masticatory muscle proprioception, mainly by the masseter muscle; joint proprioception, from the temporomandibular joint; and dental proprioception, by the periodontal ligament [4]. These three types of proprioception are mediated by the trigeminal nerve. The neuroanatomical substrates have been described in the rat, which originate from trigeminal nucleus, projecting to all levels of the spinal cord [5,6], and from different cerebellar areas, which send fibers to the vestibular nuclei [7]. Such data strongly support the hypothesis of functional implications in postural function.

The literature evaluating the impact of the mandible on postural control reports contradictory conclusions. Some studies have suggested that postural stability is influenced by dental occlusion, jaw position [8,9], and temporo-mandibular disorders (TMD) [10]. These are supported by studies showing that mandibular position can influence head position via the sterno-cleido-mastoidian muscle [11], and that TMD

* Corresponding author at: Laboratoire de Neurosciences Sensorielles et Cognitives, UMR 7260, Aix-Marseille Université, Pôle 3C, Case B, 3, Place Victor Hugo, 13331, Marseille Cedex 3, France.

E-mail addresses: paya.argoud.orthodontie@gmail.com (M. Paya-Argoud), corinne.tardieu@ap-hm.fr, corinne.tardieu@univ-amu.fr (C. Tardieu), francois.cheynet@ap-hm.fr (F. Cheynet), anne.raskin@ap-hm.fr, anne.raskin@univ-amu.fr (A. Raskin), liliane.borel@univ-amu.fr (L. Borel).

[1] Present address: Faculté d'Odontologie, Lyon 1 Claude Bernard, 11, rue Guillaume Paradin, 69372 Lyon, France.

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impairs the upper cervical range of motion [12]. Moreover, manipulated occlusion position is associated with deviations of the spine position, in humans [13], as well as in animals [14]. On the contrary, other studies have reported a lack of correlation between dental occlusion or temporo-mandibular disorders on posture [15–18] and gait control [19]. We postulate that such contradictions in the literature may be due to the fact that studies dealing with the impact of mandibular changes on postural control cover only part of the proprioceptive mandibular system.

Studies reporting a relationship between occlusion and postural control have suggested that the influence of dental occlusion on posture depends on the difficulty of the postural task and on the sensory cues available to stabilize body in space. Specifically, dental occlusion comes into effect in dynamic postural conditions [20–22] and its importance grows as the other sensory cues become scarce, i.e., in the absence of visual cues or when the use of proprioceptive leg information is disturbed [20].

The present experiment investigated whether drastic mandibular changes resulting from orthognathic surgery (including dental, joint and muscular afferents), modified postural control. Orthognathic surgery is a surgical act of the head aimed at refocusing the maxillary and/or mandibular bones bases in the three planes of space, and at balancing mandibular proprioception. In general, the specific role of the cranio-mandibular system in postural control has focused on the deleterious effects caused by malocclusions or TMD. To answer this question, we analyzed the impact of improved mandibular position on posture during a simple static task consisting of standing upright. We hypothesized that drastic mandibular changes have major effects, resulting in an improvement of postural control.

This approach also allowed the analysis of the adaptive reweighting of sensory cues in postural stabilization after orthognathic surgery. Based on the previous studies cited above, the present hypothesis was that orthognathic surgery leads to more important postural changes in the absence, than in the presence, of visual cues, and that dental proprioception represents a minor participation in comparison with the rest of the proprioceptive mandibular changes.

The aim of the current study was to determine whether drastic mandibular changes, resulting from orthognathic surgery, modified postural control. The primary outcome was to compare the effect of orthognathic surgery on postural stabilization in a static task, consisting of standing upright. As a secondary aim, the analyses focused on head orientation.

2. Materials and methods

2.1. Participants

The study sample was obtained from patients at the Department of Maxillofacial Surgery who required orthognathic surgery. A full explanation of the study aims and procedures was provided to each patient and written, informed consent was obtained. The study was approved by local ethics committee (CPP Sud Méditerranée I). The sample size was determined on the standard deviation for the mean spectral power density measure, as calculated from a previous study [20] with a significance level of $\alpha = 0.05$ and 90% power level. Twenty-two patients were included: 6 men (aged 23.8 ± 5.0 years (mean ± SD); height: 179.5 ± 8.0 cm; body weight: 69.3 ± 11.3 kg) and 16 women (aged 26.2 ± 4.2 years; height 167.8 ± 7.2 cm; body weight: 63.8 ± 8.3 kg). Orthognathic surgery was needed to treat dysmorphic jaws in sagittal dysmorphy (class II (n = 10), class III (n = 10) Fig. 1) or vertical dysmorphy (n = 2). Participants were included if they did not have vertigo, tinnitus, acute cephalic pain, TMD, occlusal instability, physical, neurological or sensory disorders, musculoskeletal impairment in the past two years, or medication that might influence balance.

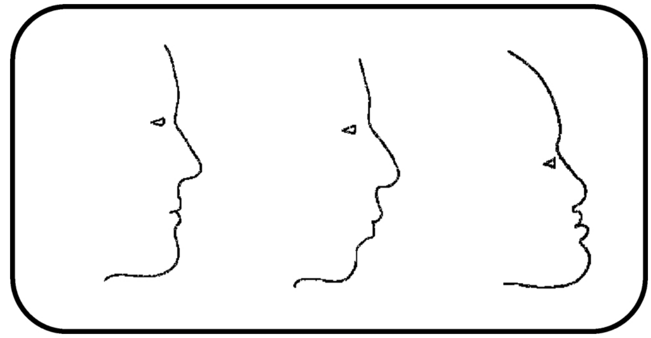

Fig. 1. Skeletal classification of sagittal abnormalities (*Middle* retrognathia: class II; *Right* prognathia: Class III) compared to normality (*Left* Class I).

2.2. Experimental protocol

To determine the effect of orthognathic surgery on postural control, analyses focused on upright stance stabilization and head orientation. Postural recordings were performed with the participants standing quietly, without making voluntary gestures, and with their hands held in a natural position along the vertical body axis. To analyze the particular weight of the dental sensory system within different mandibular sensory information, the postural performance of participants was examined under 4 experimental conditions: 2 occlusal conditions: Occlusion (OC), i.e., when the maximum number of teeth were in contact with the closed mouth, and Rest Position (RP) i.e., when there was no dental contact while the mouth was slightly open after swallowing (participants were required to maintain this position and no cotton rolls were employed to avoid involving dental proprioception); and 2 visual conditions: Eyes Open (EO) and Eyes Closed (EC). In the EO condition, participants fixated on a visual target placed 3 m in front of them, at eye level, to prevent exploratory saccades. In the EC condition, they were asked to imagine the position of the memorized visual target. The different experimental conditions (EC-OC, EC-RP, EO-OC, EO-RP) were repeated three times and presented in a randomized order. Between two trials, a rest period of 2 min was observed to avoid muscle fatigue. Patients were tested two times: before surgery and 2.5 months after, to allow for functional muscular recovery after surgical trauma [23].

2.3. Data acquisition and processing

Static posturography was performed with participants standing in a standardized position (bare-foot, feet 30° apart) on a stable force-plate (Médicapteurs, Nice, France) sensing the vertical force exerted by the feet on the ground during upright stance. The displacement of the center of foot pressure (CoP) in the anteroposterior and mediolateral directions was sampled at 40 Hz for 25.6 s. Data processing were carried using PosturoPro and Win Posture software. Postural performance was quantified using the body sway area (the area of the confidence ellipse including 95% of the CoP displacements, mm^2), the velocity of the CoP (mm/s) and the spectral power density of the recorded signal in three frequency bandwidths (0.05-0.5 Hz, 0.5–1.5 Hz, and 1.5–10 Hz, arbitrary units: AU, which corresponded to the slowest, medium, and highest movements, respectively) in the sagittal and in the frontal planes. A wavelet analysis was performed yielding a three-dimensional time-resolved and frequency-resolved chart of the instant power of the recording. These steps for analyzing body sway are illustrated in Fig. 2. The procedure for processing sway parameters has been described previously [20,24]. Finally, the possible changes of the average position of the participant was analyzed using the x and y coordinates of the CoP.

Head orientation was measured with the participants standing upright and barefoot on a landmark, with their back near a white wall, to

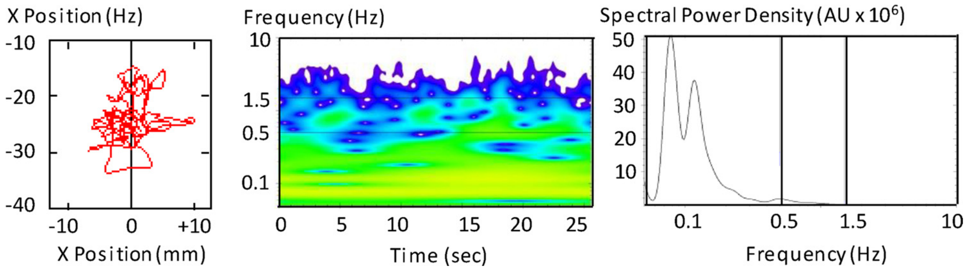

Fig. 2. Posturographic recording analysis. *Left* stabilogram showing body sway area. *Middle* three-dimensional chart obtained by wavelet analysis. Time is represented on the abscissa, and frequency is represented on the ordinate. Spectral power density is color coded. *Right* spectral power density versus frequency plot. This example illustrates a recording from a test in static eyes closed condition, and in occlusion condition, recorded before orthognathic surgery.

acquire frontal photographs. The camera (Nikon Coolpix S1, Nikon, Sendai, Japan) was fixed at 3 m from them with the same focal length to obtain greater reproducibility of the images and to avoid image distortion. The images were analyzed using graphic designed software (Canvas, ACD Systems, Florida, USA), with a precision of 0.4°. The angular position of the head in the frontal plane (in degrees) was computed as the deviation of the external intercanthal line on the photograph (IL), with respect to a horizontal line on the photograph (H), calculated compared to a vertical line (V) given by a line hanging on the wall next to the participant as a vertical reference, using the following formula: α = IL-90-(180-V), where 90° and 180° were the true horizontal and vertical, respectively. A 0° angle indicated a lack of deviation with respect to the true horizontal axis. Since head orientation in the frontal plane could be deviated either clockwise or counterclockwise, head orientation in the frontal plane was defined as an absolute value.

2.4. Statistical analysis

Data distribution were tested for normality using the Shapiro-Wilk test. Postural parameters (sway area, velocity of the CoP, spectral power density, average position of the CoP) and head orientation in the frontal plane were analyzed using three-way repeated-measures of variance (ANOVA), with Session (Preoperative, Postoperative), Visual condition (EO, EC), and Occlusal condition (OC, RP) as within-subjects factors. Results were considered statistically significant at $p < 0.05$.

3. Results

3.1. Effect of orthognathic surgery on postural responses – mean spectral power density

Repeated-measures ANOVA conducted on the wavelet transformation data in the anteroposterior direction indicated that Session constituted a main effect for the variation of the mean spectral power density for the first ($F(1,21) = 7.32$; $p = 0.013$), second ($F(1,21) = 12.89$; $p = 0.002$), and third ($F(1,21) = 12.07$; $p = 0.002$) frequency bands. Spectral power density was significantly decreased after orthognathic surgery (Fig. 3). These data indicate a decrease of the energetic cost of maintaining an upright posture, underlying an improvement of postural control. In addition, a main effect of the Visual condition was found for the all frequency bands ($F(1,21) = 12.18$; $p = 0.002$; $F(1,21) = 24.62$; $p < 0.0001$ and $F(1,21) = 9.78$; $p = 0.005$, respectively) with lower signal power density in EO than in EC condition, showing a better postural control in the EO condition. Finally, a main effect of the Occlusion condition showed a trend toward significance ($F(1,21) = 12.18$; $p = 0.055$) for the first frequency, and significant results for the second ($F(1,21) = 4.91$; $p = 0.038$), and third ($F(1,21) = 12.81$; $p = 0.04$) bands. The spectral power density was lower in the RP than the OC condition, indicating that postural stabilization was more efficient in the RP condition. A significant Session × Visual condition interaction was reported in the second frequency band ($F(1,21) = 10.03$; $p = 0.004$), where, after surgery, mean spectral power density reduction was greater in the EC condition (35.9 ± 15.0%) than in EO condition (10.4 ± 16.7%) ($p = 0.0046$).

ANOVA performed on the wavelet transformation data in the mediolateral direction showed no significant effect of Session and Occlusal condition over all three frequency bands. The only main effect was related to the Visual condition, with better postural control in the EO than EC condition for the second ($F(1,21) = 19.31$; $p < 0.0002$) and third ($F(1,21) = 9.00$; $p = 0.0068$) bandwidths, as found in the anteroposterior plane.

3.2. Effect of orthognathic surgery on postural responses – velocity of the CoP

The velocity of the CoP revealed a significant effect of the Visual condition [$F(1,21) = 62.55$; $p < 0.0001$]. The effect of Session showed a trend to significance [$F(1,21) = 12.77$; $p = 0.055$]. The ANOVA also revealed a significant interaction Session x Occlusal condition, suggesting that the consequences of orthognathic surgery on the velocity of postural oscillations differed according to occlusal conditions [$F(1.21) = 7.22$; $p = 0.014$]. Indeed, detailed analysis revealed that surgery had a larger impact on the velocity of the CoP in the RP condition [$F(1.21) = 8.92$; $p = 0.007$] (Fig. 4). Although less significant, these results confirm those of mean spectral power density data.

3.3. Effect of orthognathic surgery on postural responses – sway area

This traditional posturography data collected under static conditions were less discriminating, since the variance analysis showed that sway area did not significantly differ after surgery. The only significant effect obtained was on Visual condition, with greater sway area in EC condition than in EO condition [$F(1.21) = 9.76$; $p = 0.005$].

3.4. Effect of orthognathic surgery on postural responses – average position of the centre of pressure

Repeated-measures ANOVA carried out on the x and y coordinates of the CoP showed that the average x and y position of the participants did not differ significantly after surgery, whatever the visual and the occlusal conditions.

3.5. Effect of orthognathic surgery on head orientation

The ANOVA revealed a significant interaction of Session x Occlusal condition x Visual condition [$F(1,21) = 8.80$; $p = 0.007$]. Planned comparisons revealed that the effect of surgery significantly improved head orientation when patients were tested in EC and in OC condition ($p = 0.019$), i.e., in the absence of visual references, but in presence of occlusal references (Fig. 5).

4. Discussion

The present study investigated changes in postural stabilization and head orientation in patients with dysmorphic jaws tested before, and 2.5 months after, orthognathic surgery in a static task consisting of

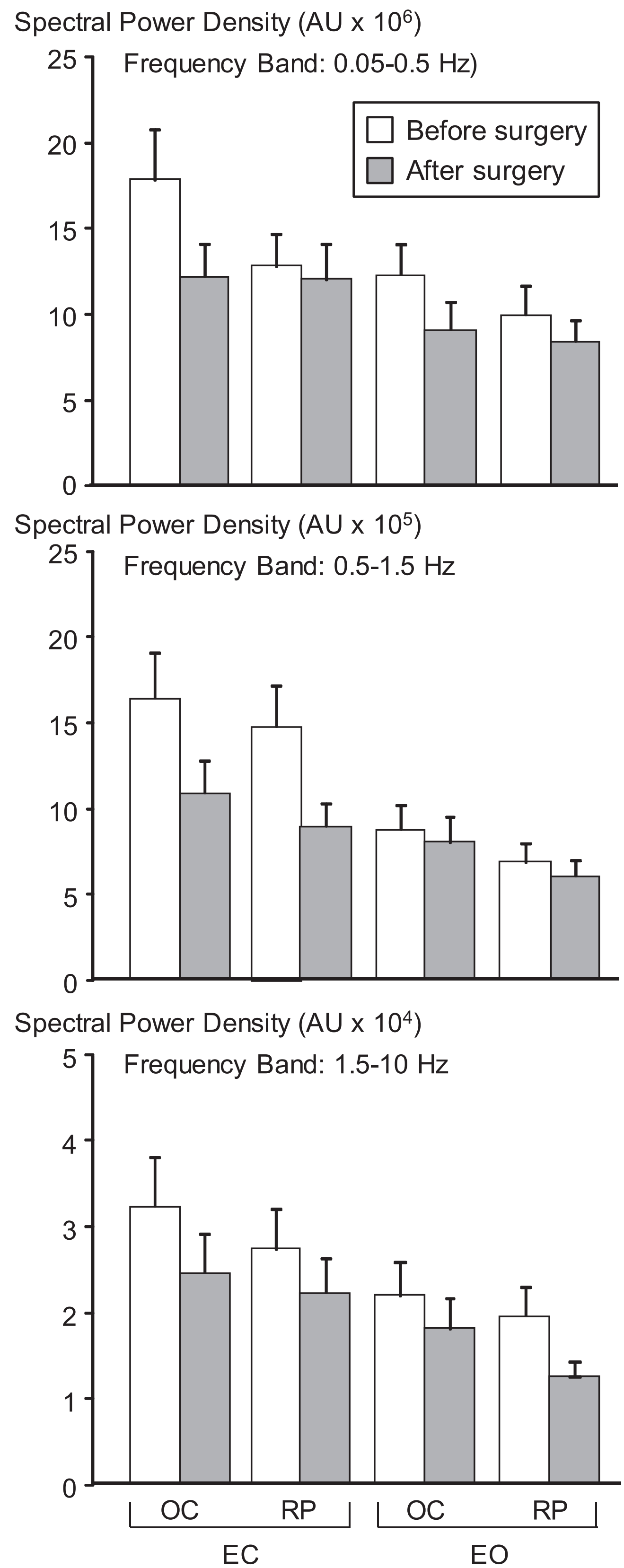

Fig. 3. Effect of orthognathic surgery on postural performance. Spectral power density for the anteroposterior direction in the three bands for patients before (open histograms) and after (filled histograms) surgery compared for each occlusal (Occlusion: OC, Rest Position: RP) and visual (Eyes Open: EO, Eyes Closed: EC) condition. Vertical bars represent the standard error. * $p < 0.05$.

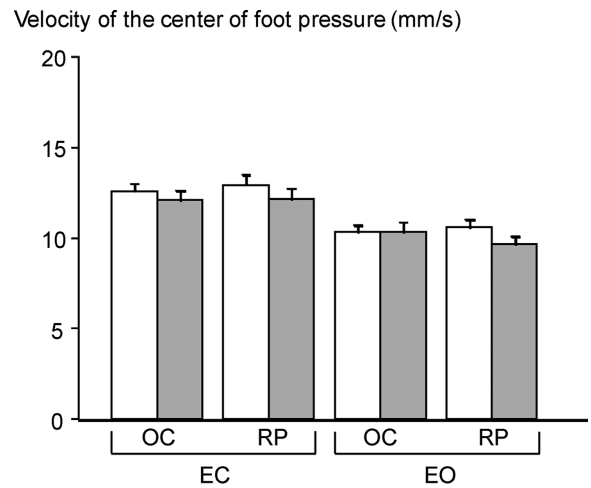

Fig. 4. Effect of orthognathic surgery on average velocity of the CoP compared for each experimental condition. Same conventions as in Fig. 3.

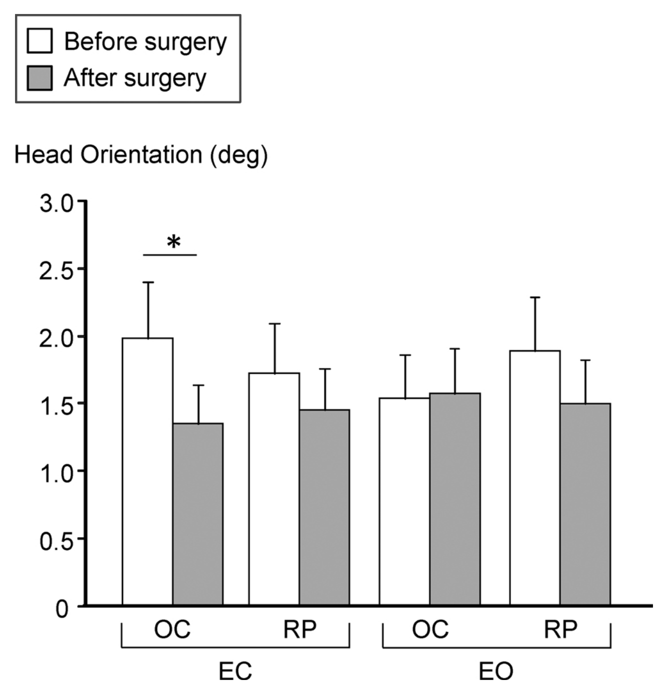

Fig. 5. Effect of orthognathic surgery on head orientation in the frontal plane. Head orientation for patients before and after surgery compared for each experimental condition. Same conventions as in Fig. 3.

standing upright.

4.1. Effect of orthognathic surgery on postural responses

Analyzes based on the wavelet transformation data showed a reduction in the spectral power density of body sway in the anteroposterior direction in the three frequency ranges. These results highlight a postural improvement in maintaining an upright stance. Such a postural improvement was reported for all visual (EO and EC) and occlusal (OC and RP) conditions.

The effect of postural control modification in a static postural condition, after orthognathic surgery, is all the more interesting regarding the literature dealing with the consequences of malocclusions on posture. Studies have shown that the influence of dental occlusion on postural control is secondary in static conditions, while it is higher under more challenging conditions, such as dynamic conditions

[20,22]. Very few studies have shown changes in static postural responses with the eyes closed, after changes in dental occlusion [25,10]. These differential effects on postural control could be accounted for by the kind of intervention (e.g. drastic mandibular changes versus dental occlusion and temporo-mandibular disorders). The current finding that postural stability is improved under static conditions after orthognathic surgery highlights the major role of mandibular proprioception in postural control. Direct and indirect trigeminal projections to different cerebellar areas and on the vestibular nuclei complex, particularly the inferior vestibular nucleus projecting on the spinal cord, could underlie the functional changes reported here.

In addition, the present results indicated that postural stability was improved after orthognathic surgery in both the EO and EC conditions, and improvements were greater when visual cues were absent. Therefore, after orthognathic surgery, visual cues play a major role in static postural control. However, considering the improved stability with the eyes open, it was predicted that the improved postural stability after surgery resulted from a reweighting of sensory cues involved, with an increased importance for the proprioceptive mandibular information. All the present data provide further arguments in favor of our hypothesis that the greater the mandibular proprioceptive changes, the greater the effects on posture.

Furthermore, the current data indicate that, although the positive effects of surgery on postural stabilization are observed in both occlusal conditions, they are more important in RP condition, i.e., without dental contact. Therefore, it seems that proprioceptive cues coming from the mandibular muscles and joints are more involved in postural changes. Consequently, in these experimental conditions, the weighting of proprioceptive cues linked to dental proprioception appears to be lower than those of the mandibular musculo-articular system. These conclusions are in agreement with those reported in a previous study dealing with the effect of dental occlusion perturbation on postural control [20].

On average, the present results indicate that orthognathic surgery did not change the position of the center of pressure. Also, less significant and no significant effects were found for the velocity of the CoP and the sway area, respectively. These results confirm previous data indicating that wavelet analysis parameters are more discriminating than the classic ones [26,27].

4.2. Effect of orthognathic surgery on head orientation

After orthognathic surgery, head orientation in the frontal plane was improved, where the external intercanthal line was closer to the true horizontal line. As compared to preoperative data, head orientation was improved when patients were tested EC and in OC condition. Since orthognathic surgery improves mandibular stability by refocusing the bones bases, it is suggested that, in the OC condition, the dental contact provided a new reference allowing the head to be oriented in space when visual references of verticality and horizontality were lacking. These data provide the first description of an improvement of head orientation in the frontal plane after mandibular proprioceptive changes from the orthognathic surgery, in the standing subject. Previous studies dealing with the effects of orthognathic surgery on natural head posture focused on pharyngeal respiratory changes, which were related to postoperative changes in the head sagittal plane [28,29]. To our knowledge, only one study suggested a corrected frontal head posture after orthognathic surgery in patients with facial asymmetry, but the experimental conditions were different from the current ones, with subjects sitting on a chair and having visual feedback in a mirror [30]. The present results argue for a major effect of balanced mandibular proprioception on the orientation of the head in space, in the frontal plane, and this improvement may be supported by muscle modification [11]. Such changes in head orientation may facilitate the functioning of other sensory systems carried by the head, including the vestibular system. In this way, mandibular proprioception should be viewed as a contributor in postural control, through the ability to control the head platform orientation.

The present study has some limitations. Since patients with different types of dysmorphy were included, the severity of morphological shifts and therefore the variability of surgical correction before and after surgery, were not taken into account. Indeed, 2.5 months after orthognathic surgery, the functional muscular recovery after surgical trauma could be variable depending on the amplitude of the correction, and thus differentially influence the body posture.

In conclusion, the current study has shown that oro-facial muscular harmonization, following orthognathic surgery, improves head orientation and postural stabilization under static conditions at 2.5 months. The present data suggest that, under such conditions, the weight of proprioceptive cues linked to the mandibular system may be sharply enhanced to (1) constitute a new reference frame to orient the head in space, in darkness; (2) improve postural stabilization, even in the presence of visual cues. In addition, these results suggest that different mandibular proprioceptive information may have different functional goals: the sensory information linked to dental occlusion may mainly contribute to head platform orientation, while proprioceptive cues coming from the mandibular muscles and joints could be mainly involved in postural stabilization. Further studies should be conducted to analyze the consequences of orthognathic surgery on postural stabilization in the moving subject, to gain a more accurate picture of the role of mandibular proprioception on postural regulation.

Conflict of interest

There are no conflicts of interest.

Acknowledgements

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