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Variation between natural head orientation and Frankfort horizontal planes in orthognathic surgery patients: 187 consecutive cases

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Abstract. The purpose of this study was to assess the relationship between the Frankfort horizontal (FH) and natural head orientation (NHO), their correlation between patients' malocclusion, and the impact of counterclockwise rotation (CCW) on the FH-NHO angle variation after orthognathic surgery. An evaluation of 187 consecutive patients was performed at the Maxillofacial Institute (Teknon Medical Center, Barcelona). FH-NHO° was measured pre- and postoperatively at 1 and 12 months, after three-dimensional (3D) superimposition using a software (Dolphin®). Patients were classified as follows: 3.2%, 48.7% and 48.1%, class I, II and III, respectively. Baseline FH-NHO° was significantly positive for patients with dentofacial deformities (2.73° ± 4.19 (2.12–3.33°, $P < 0.001$). The impact of orthognathic surgery in FH-NHO° was greater in class II when compared with class III patients, with a variation of 2.04° ± 4.79 ($P < 0.001$) and −1.20° ± 3.03 ($P < 0.001$), respectively. FH-NHO° increased when CCW rotational movements were performed ($P = 0.006$). The results of this study suggest that pre- and postoperative NHO differs from FH in orthognathic patients. The angle between FH and NHO is significantly larger in class III than in class II patients at baseline, which converges after orthognathic surgery when CCW rotation is performed. Therefore, NHO should be used as the real horizontal plane when planning for orthognathic surgery.

Keywords: Patient positioning; Orthognathic surgery; Dentofacial deformities; Three-dimensional imaging; Cone-beam computed tomography.

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Head orientation is a key factor in cephalometric and facial analysis for orthodontic and orthognathic surgery treatment planning, because it influences the anteroposterior perception of the maxillomandibular complex and may result in an incorrect diagnosis.[1]

Various reference planes have been described for head orientation, both extracranial and intracranial.[2] One of the most commonly used is the Frankfort horizontal (FH) plane, which was first described in the Frankfort Craniometric Agreement (1882),[3] and was defined as a plane that passes through the upper rim of the external acoustic meatus (porion, Po) and the lowest point of the orbital rim (orbitale, Or).[2,3] However, a potential variability has been observed with the FH plane and similar planes that use only intracranial landmarks, because the anatomical landmarks are influenced by individual biological variability.[4] The FH plane has been found to deviate from the true horizontal plane depending on head inclination, especially in patients with dental or facial deformities.[5]

Extracranial reference planes, such as the natural head position (NHP) and natural head orientation (NHO) are alternatives to the intracranial reference planes, enabling the use of true vertical and horizontal lines for clinical facial analysis.[6] The concept of NHP was introduced in cephalometric analysis in the 1950s and is defined as the physiological position of the head that feels most natural to a living person.[6,7] Thus, NHP has been described as the ideal reference in cephalometric analysis due to its reliability and reproducibility, as it focuses on a distant point and therefore is not influenced by cranial base variability.[5,8] Although there are different methods for the patient to achieve NHO, the most common is to indicate the individual to look straight ahead at a point in front of them at eye level (e.g., looking into a mirror).[6] However, there is a slight subjectivity in head orientation as it depends on the patient who has to be told how to achieve a natural posture, and it sometimes requires certain experience of the clinician.[9]

Furthermore, NHO is influenced by other factors such as the visual and vestibular apparatus, local proprioceptors, craniocervical posture, facial and neck muscles, temporomandibular joints, maxillo-mandibular relation and dental occlusion.[10] Consequently, because the maxillomandibular relation is one of the defining factors of head positioning, NHO should theoretically change after orthognathic surgery, and even more when counterclockwise (CCW) rotational movements are performed, due to its effect on the accommodation of the head on the cervical column.[11,12]

Therefore, the main objectives of this research were to assess the relationship between FH and NHO and its correlation between patients' dental class, and the impact of CCW rotation on the FH-NHO angle variation after orthognathic surgery.

Materials and methods

To address the research purpose, the investigators designed and implemented a retrospective cohort study. The study population consisted of consecutive patients with dentofacial deformities who underwent orthognathic surgery (either mono- or bimaxilar) at the Maxillofacial Institute (Teknon Medical Centre in Barcelona, Spain) during 2019. Clinical data and three-dimensional (3D) radiological images were obtained from the Institute's database. Each patient provided written informed consent to access their cone-beam computed tomography (CBCT) data. This study was approved by the Teknon Medical Hospital Institutional review board (IRB) (Barcelona, Spain) (Ref.2019/60-CMF-TEK),and was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its subsequent amendments. All participants signed an informed consent agreement.

Patients of any gender, over the age of 18 years with completed growth of the maxillofacial complex and who underwent orthognathic surgery (mono- or bimaxillary) were included in the study. Patients with craniofacial syndromes or craniocervical posture pathology, patients with missing follow-up photographs and CBCTs or those who were not willing to sign the informed consent were excluded from the study.

Presurgical 3D planning protocol, as described elsewhere, was performed with a three-party software and the upper incisor soft-tissue nasion plane (UI-STP) was used as an absolute reference to guide the anteroposterior positioning of the maxillomandibular complex.[13] Intermediate and final surgical splints were designed and printed in house. Patients were operated on under general anaesthesia by the same surgeon (FHA) following the mandible-first proto-

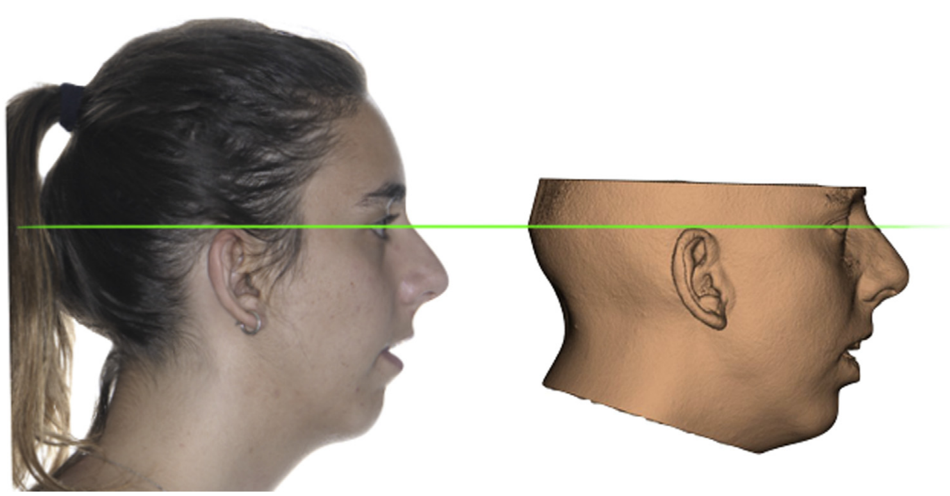

Fig. 1. Extracranial true horizontal line used by the clinicians to orient the cone-beam computed tomography. A true horizontal line was traced on the photograph (lateral view), passing through two points: the lateral canthus of the eye and at a determined point of the helix (auricular point, which varied depending on each patient).

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col. A mandibular bilateral sagittal split osteotomy (BSSO) was performed using the Dal Pont–Obwegeser method and/or a maxillary LeFort I osteotomy was carried out using the minimally invasive 'twist technique' described elsewhere.[14] Surgical data was collected regarding type of mono- or bimaxillary surgery and whether clockwise or CCW rotation movements were performed.

All included patients had followed the standard pre- and postoperative imaging workflow protocol for orthognathic surgery of the Department, which involves facial and occlusal pictures and CBCT at three time points: preoperatively (T0) and postoperatively at 1- (T1) and 12- (T2) months follow-up. These two postoperative time points were chosen in order to evaluate the short- and long-term effects of orthognathic surgery in NHO.

The CBCT scans were performed using an i-CAT Vision system (iCAT, Imaging Sciences International, Hatfield, PA, USA). For both records (CBCT and photographs), patients were previously instructed by trained clinical personnel in order to achieve a proper head orientation: they were indicated to adopt a standing position and to look straight ahead at a point at eye level located on the wall in front of them (1 m away).[6] In addition, a 2-mm centric relation wax bite was placed to avoid occlusal interferences.

Each patient had three CBCT datasets (preoperative (T0), postoperative at 1 month (T1) and postoperative at 12 months (T2)). Data were primarily saved in DICOM (Digital Imaging and Communications in Medicine) format using 3D software (Dolphin Imaging, version 11.95 premium, Chatsworth, CA, USA). Routine photographic records in NHO were used to orient and match up the CBCT 'virtual patient' ('soft tissue layer') as follows: a true horizontal line was traced on the photograph (lateral view), passing through two points: the lateral canthus of the eye and at a determined point of the helix (auricular point, which varied depending on each patient). Then, this true horizontal line from the photographs were transferred to the CBCT 'soft tissue virtual patient', resulting in a re-oriented CBCT 'virtual patient'. This true horizontal line was used to orient the CBCT 'virtual patient' in NHO (Fig. 1). The software orientation calibration tool was used along pitch (x), yaw (y) and roll (z). Orientation of both the 'Base volume' (original DICOM) and '2nd volume' (duplicate DICOM) was undertaken to achieve the same original positions of the CBCTs ('hard tissue layer').[15] Then, the FH plane was marked as a line connecting the right porion (Po, the upper rim of the external acoustic meatus) and right orbitale (Or, the lowest point of the orbital rim) ('hard tissue layer').[3]

The angle between FH and NHO (FH-NHO°) was measured by two investigators (M.G.H. and A.V.O.) before the intervention (T0), at 1 month (T1) and 12 months follow-up (T2). Its relationship was considered positive if the FH was located above the NHO plane and negative if FH was below it (Fig. 2). In order to ensure truly accurate and reproducible measurements, the examiners tagged all virtual models independently on two separate occasions (2 weeks apart), thus avoiding inter- and intra-observer differences, respectively. Inter- and intra-class correlation analyses (ICCs) were used to calculate examiner differences and reliability.[16,17]

Statistical analysis (IBM SPSS Statistics for Windows, version 25; IBM Corp., Armonk, NY, USA) was used to investigate the relationship between FH and NHO before, and 1 month and 1 year after surgery. Descriptive analysis evaluated the most relevant statistics for all analysed variables, and a Kolmogorov–Smirnov test was used to check the normal distribution of FH-NHO dimensions. In order to compare measurements at different time points and their correlation with dental class and surgical procedure, an inferential analysis was performed using the analysis of variance (ANOVA) test and the Bonferroni correction. Two-sided *P*-values <0.05 were considered significant for all

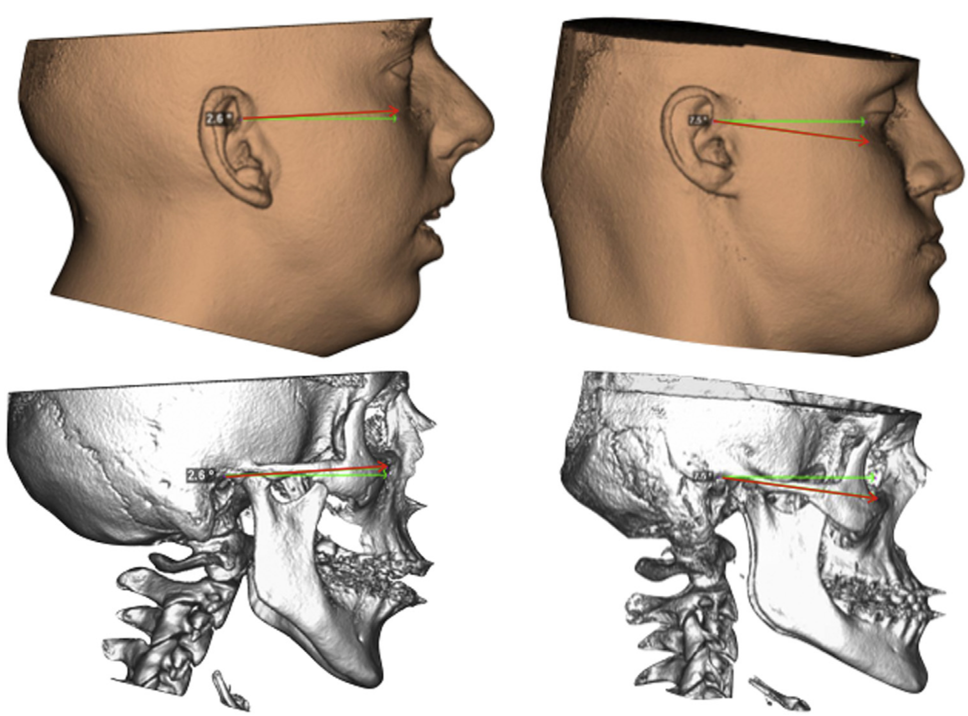

Fig. 2. Assessment of natural head orientation (NHO) and Frankfort horizontal (FH) in class II and class III patients. In these cases, NHO with respect to FH (highlighted in red) were set at 2.6° (negative) and 7.5° (positive) in class II and class III patients, respectively.

of the statistical tests. A mixed ANOVA model reached a statistical power of 98% when detecting mean differences in NHO between groups, with a medium effect size ($f = 0.25$) and a 95% confidence interval. The statistical power was 88% with a small to medium effect size ($f = 0.15$) for intra-observer variation and differences over time (T0, T1, T2).

Results

A sample of 187 consecutive patients who underwent orthognathic surgery were included in the study. The sample comprised 124 women (66.3%) and 63 men (33.7%), with a mean age of 33.9 ± 11.2 years (range 15–67). Patients were classified as dental class I (3.2%), class II (48.7%) or class III (48.1%) according to Angle's malocclusion classification.[18] All of the selected patients underwent bimaxillary (80%) or monomaxillary (20%) surgery, of whom 55.9% and 43% received a CCW and clockwise rotation of the maxillomandibular complex, respectively. No rotational movements were performed in 1% of the sample (Table 1). The ICC obtained for angle measurements was <0.11°.

The mean baseline FH-NHO° was 2.73° ± 4.19° (2.12–3.33°, $P < 0.001$). FH-NHO° was significantly positive for the population eligible for orthognathic surgery ($P < 0.001$, *t*-test). In particular, regarding FH-NHO° related to Angle's dental class, statistically significant differences between class II and III patients in each group were observed ($P < 0.001$, test F) (Fig. 3).

Regarding FH-NHO° changes after surgery, there were no significant differences for the total sample, neither at 1-month (2.86° ± 3.12) ($P = 1.000$) nor at 12-months follow-up (3.15° ± 3.19) ($P = 0.539$) (Table 2). However, a variation in FH-NHO° was observed between dental class II and III patients ($P < 0.001$) (Fig. 4). A greater impact of surgery was evidenced in class II compared with class III patients, reporting FH-NHO° changes between T0 and T2 as follows: 2.04° ± 4.79 ($P < 0.001$) and −1.20° ± 3.03 ($P < 0.001$), respectively.

No significant changes could be detected based on the type of surgery (mono- and bimaxillary surgery) ($P = 0.318$). Nevertheless, patients who received a CCW rotation in the context of a bimaxillary surgery (compared with those patients with CW or without rotational movement), FH-NHP° increased significantly ($P = 0.006$) (Fig. 5)

A multivariate model was calculated including each single independent variable in order to rule out eventual bias and confounding factors. Results showed that FH-NHO° changes significantly depend on the dental class of the patient ($P < 0.001$) and the CCW rotation performed at surgery in the bimaxillary group ($P = 0.082$) (Fig. 6).

Discussion

The head positioning of the CBCT is essential for the virtual planning of orthognathic surgery. The results of the present study show that FH is not equivalent to NHO and that a positive angle between FH-NHO exists (2.73° ± 4.19, $P < 0.001$, *t*-test). This implies that FH is located superior to the NHO plane in most cases, which is in agreement with the published literature.[5] However, when grouping patients according to dental class, class II patients showed a smaller FH-NHO angle (1.35° ± 4.29), whereas class III patients presented an increased relationship (4.15° ± 3.60) ($P < 0.001$) (Fig. 3). Emphasis should be placed when adjusting the head position of the patient during NHO registration to avoid diagnostic errors, as Class II and Class III facial types tend to compensate for their head position.[19] Class II subjects tilt their head upwards, whereas class III subjects tilt their heads downwards, thus the FH represents an upward or downward inclination in relation to the true horizontal plane, respectively.[19] Thus, it is plausible that NHO should be the 'gold standard' reference plane instead of FH, because a reliable reference plane is necessary for a correct 3D facial analysis, which becomes even more evident in patients with dentofacial deformities.[4] Needless to say, both treating orthodontists and surgeons should use the same reference plane in order to use a common terminology for treatment planning, and therefore align treatment goals, increase accuracy and improve final outcomes.

Reproducibility of NHO in the sagittal, coronal and axial planes with 3D imaging has been proven to be as reliable as with cephalometric radiographs.[17,20,21] When recording NHO three-dimensionally, a CBCT in an upright position without external immobilizers is recommended, rather than a conventional computed tomography in a supine position.[21] Although it would be desirable for patients to undergo the scan with a proper NHO, some unexpected changes in head position during the recording process are unavoidable. For this reason, new tools and softwares have been designed to record, transfer and adjust NHO properly; such as stereophotogrammetry, laser surface scanner, or digital gyroscope, among others.[17,22,23] However, the devices themselves may influence the accuracy of reorientated head position, and in some cases may cause soft tissue distortion.[20,24,25] Therefore, surgeons usually use a simple virtual skull re-orientation method according to NHO based on frontal and lateral photographic records.[26]

As stated previously, extracranial references such as NHO allow the use of true vertical and horizontal lines as optimal reference planes for surgical planning.[27,28] In this context, the authors used a soft tissue vertical line that passes through nasion soft tissue as an absolute reference to guide the anteroposterior positioning of the maxillomandibular complex, further described elsewhere.[11]

Besides, when Class I was obtained after surgery, FH-NHO angulation in-

Table 1. Descriptive characteristics of the studied sample.

	$n = 187$	%
Gender		
Male	63	33.7
Female	124	66.3
Type of dentofacial deformity		
Class I	6	3.2
Class II	91	48.7
Class III	90	48.1
Type of interventions		
Bimaxillary surgery	149	79.6
Monomaxillary surgery	38	20.4
Rotational movements		
CW	80	43
CCW	104	55.9
No rotation	3	1.1
Age (mean ± SD)	33.9 ± 11.2	

CW, clockwise rotation; CCW, counterclockwise rotation; SD, standard deviation.

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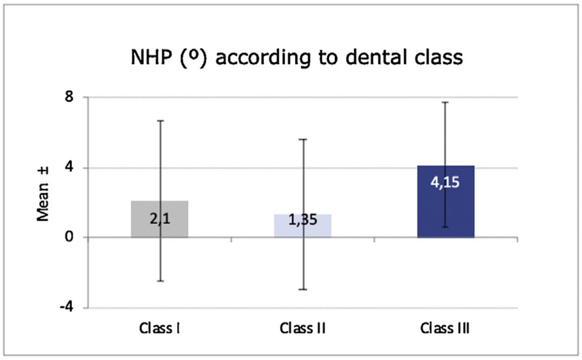

Fig. 3. Mean angle between Frankfort horizontal and natural head orientation (FH-NHO°) for class I, II and III patients. NHP, natural head position.

creased in class II patients (3.40° ± 3.41), while it reduced in class III (2.95° ± 3.04). Remarkably, final FH-NHO relationship for both groups converged after treatment yielding to a more similar value, which was close to the overall postsurgical FH-NHO value of the entire sample (3.15° ± 3.19), which can be considered a close approximation to the standard FH-NHO relationship of class I patients (Fig. 4). Therefore, this relationship was still positive, which reaffirms the earlier statement that FH is not equivalent to NHO.

The relationship between the final FH-NHO° and the patients' dentofacial deformity was greater in class II than in class III patients, which reverses the initial situation of the angle (Fig. 4). This is explained by the previous adaptation of the cranio-cervical posture, facial and neck muscles, temporomandibular joints, visual and vestibular apparatus and local proprioceptors which counteract the presurgical dental class and pattern of maxillomandibular imbalance.[12,29]

To our knowledge, this is the first study to evaluate the impact of CCW rotation on FH-NHO° after orthognathic surgery. Although head and neck posture changes after orthognathic surgery have been widely reported in the literature,[30,31] our study has demonstrated that CCW rotation of the maxillomandibular complex is significantly related to FH-NHO° changes ($P = 0.006$) (Fig. 5), which suggests that occlusal plane changes have an impact on the cranio-cervical posture.[11] This is explained by the patients' tendency to adapt their cervical spine based on their specific underlying dentofacial deformity. Then, once it is surgically corrected, there is no need for this adaptation.

The type of surgery did not induce significant changes in the NHO, but the rotational movements performed did. Therefore, when CCW rotation was performed in the context of bimaxillary surgery, FH-NHO angulation increased at 1-month follow-up (from 1.83° to 2.81°) and to a greater extent at 12-month follow-up (from 2.81° to 3.32°) (Fig. 5). Similarly, the same pattern was observed in class II patients: FH-NHO° increased immediately after surgery and even further at long-term follow-up (T0–T1–T2: 1.35°–2.84°–3.40°, respectively). However, FH-NHO° decreased significantly after surgery and remained stable over time in class III patients (T0 − T1 = T2, from 4.15° to 2.95°) (Fig. 4). This suggests that the period of adaptability of the abovementioned influencing factors in NHO is longer in class II patients when CCW rotation is performed than in class III patients.

A potential limitation to this study was the reliability analysis of NHO determination and measurement assessment. To overcome this problem, emphasis was placed on landmark identification and angle measurement. In order to ensure truly accurate and reproducible measurements, and to avoid landmark errors produced by magnification and distortion, both examiners (M.G.H. and A.V.O.) previously calibrated each virtual model by independently tagging landmarks on two separate occasions (2 weeks apart), thus avoiding inter- and intra-observer differences, respectively. ICC (inter- and intra-) analyses were performed throughout the present study.

With regard to NHO re-orientation reliability, 3D imaging techniques do not maintain the previously recorded NHO of the patient; therefore, subjective re-orientation by expert clinicians of the 3D images is needed (Fig. 1).[17] Considering this, some authors[17] have determined a moderate reliability for both intra- and inter-rater reliability in re-orientating 3D images to the estimated natural head position.[17] In their study, Zhu et al.[17] found a small median ICC difference for roll and yaw, but larger for pitch. This means that clinicians tend to position the chin posteriorly (6.3 ± 5.2 mm), reducing the perceived severity of the dentofacial deformity in the antero-posterior direction. Therefore, this data highlights the importance of orientating the 3D images prior to measuring and planning. Both calibration and ICC analyses followed those from Lagravere et al.,[16] and Zhu et al.,[17] previous studies, and measurements were taken in the three axes (x, y, z) as mentioned above. In this study, the ICC obtained by the authors for the angle variability was <0.11°. Thus, our ICC analyses for this study are in line with those previously accepted in the literature, which demonstrates the accuracy of the followed approach on NHO determination and landmark identification among different examiners.[16]

In conclusion, the results of this study suggest that pre- and postoperative NHO differs from FH in orthognathic patients. The angle between FH and NHO is significantly larger in class III patients than in class II patients at baseline, which converges after orthognathic surgery when CCW rotation is performed. Therefore, NHO should be used as the real horizontal plane when planning for orthognathic surgery.

Table 2. Mean changes in the angle between Frankfort horizontal and natural head orientation (FH-NHO°) short term (T1–T0), stability (T2–T1) and long term (T2–T0) for dental class II and III patients.

	T0	T1	T2	T1–T0	T2–T1	T2–T0
Class II	1.35 ± 4.29	2.84 ± 3.22	3.40 ± 3.41	1.48 ± 4.08 **P < 0.001***	0.56 ± 2.77 $P = 0.121$	2.04 ± 4.79 **P < 0.001***
Class III	4.15 ± 3.60	2.95 ± 3.08	2.95 ± 3.04	−1.20 ± 2.80 **P = 0.004**	0.01 ± 2.42 $P = 1.000$	−1.20 ± 3.03 **P = 0.015***

Statistically significant results are presented in bold; $P < 0.05$. Mean ± SD and t-test from analysis of variance (ANOVA) and Bonferroni correction.

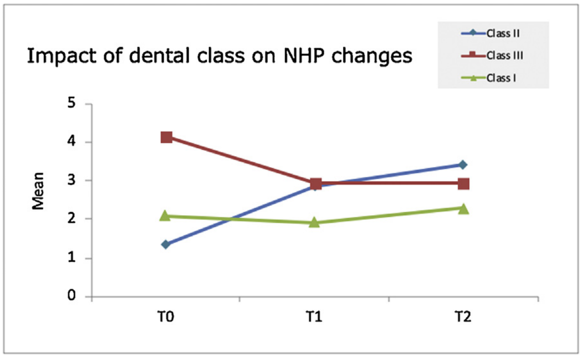

Fig. 4. Impact of dental class (I, II and III) on the angle between Frankfort horizontal and natural head orientation (FH-NHO°) over time (T0, T1 and T2). NHP, natural head position.

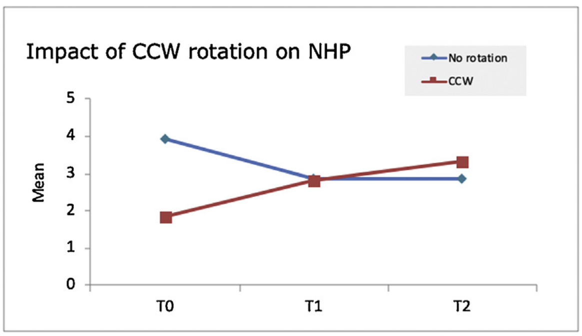

Fig. 5. Impact of counterclockwise (CCW) rotation on Frankfort horizontal and natural head position (FH-NHP°) over time (T0, T1 and T2).

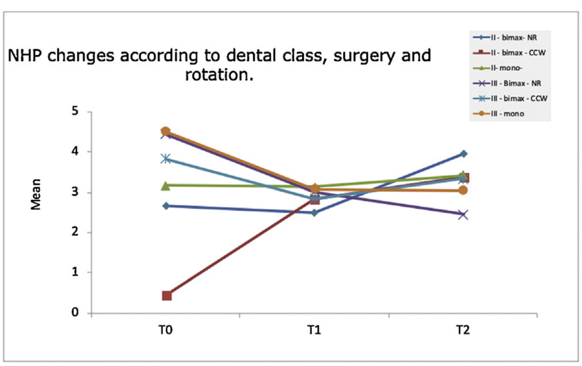

Fig. 6. Multivariate analysis of changes in the angle between Frankfort horizontal and natural head orientation (FH-NHO°) over time according to dental class (I, II or III), type of surgery (mono- or bimaxillary) and rotation [no rotation (NR) or counterclockwise (CCW)], in the short and long term.

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Competing interests

There are no competing interests.

Ethical approval

This study was approved by the Teknon Medical Hospital Institutional review board (IRB) (Barcelona, Spain) (Ref.2019/60-CMF-TEK).

Patient consent

Patient written informed consent was provided to access the CBCT database.

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