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ORIGINAL ARTICLE

Accuracy Assessment of Virtual Surgical Planning Comparing 3D Virtual Surgical Planning and Post-Operative CBCTs in Surgical Skeletal Class III Cases: A Retrospective Study

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ABSTRACT

Objective: To evaluate the accuracy of Virtual Surgical Planning (VSP) comparing VSPs and post-operative CBCT scans in patients undergoing bimaxillary orthognathic surgery of severe Skeletal Class III malocclusion. **Material and Methods:** Twenty-three patients (9 males and 14 females, mean age 24.1 ± 7.0 years) were selected and submitted to bimaxillary orthognathic surgery. Pre-operative VSPs and post-operative CBCTs were compared using both linear (taking into account four skeletal and six dental landmarks, each one described by the respective coordinates) and angular measures (seven planes in total). The threshold discrepancies for post-operative clinical acceptable results were set at ≤2 mm for liner and ≤4° for angular discrepancies. The mean difference values and its 95% confidence interval were identified, comparing which planned and which obtained in absolute value. **Results:** There were significant statistical differences for all absolute linear measures investigated, although only two overcome the linear threshold value of 2mm in both X and Y-linear dimensions. Linear deviations in Z-linear dimension do not reach statistical significance. All 12 angular measures reach the statistical significance, although none overcome the threshold angular value of 4°. Angular deviation for roll register the higher accuracy in contrast to pitch and yaw. **Conclusion:** Virtual surgical planning is a reliable planning method to be used in orthognathic surgery field; as a matter of fact, although some discrepancies between the planned on the obtained are evident, most of them meet the tolerability range.

Keywords: Orthodontics; Malocclusion, Angle Class III; Epidemiologic Methods.

Introduction

Skeletal Class III malocclusion is a condition in which early treatment is often advocated due to fact that in an early age, the skeletal responsivity to corrective orthopedic forces is good, leading to satisfactory results, especially in the short-term [1-4].

Despite this, long-term stability results are not always good due to fact that poor patience compliance [5] and unfavorable skeletal Class III pattern growth (rate and duration of mandibular lengthening) could not be previewed in some cases [6].

Although some authors developed some orthopedic approaches, even with the use of miniscrews [7-10] and different expansive protocol to disarticulate maxillary jaw, making it more responsive to facemask forward protraction [11-16], in about 25% of the cases the Class III growth pattern returns [6] leading to unesthetic facial condition, poor occlusion, periodontal problems [17] and psychological problems such as low self-esteem, stress, anxiety, problems undermining the quality of life [18-20].

In these cases, the surgical bimaxillary orthognathic approach becomes the only possibility to solve severe Class III malocclusions with good facial aesthetics, especially in cases characterized by a high-angle, skeletal open-bite, skeletal asymmetry and thin periodontal biotype. As a matter of fact, in these patients, a camouflage orthodontic therapy would cause an unsatisfactory result under esthetic and biological points of view [21].

The surgical approach of skeletal Class III malocclusions sees the participation of both orthodontist and maxillo-facial surgeon, with the latter who has the aim to repositioning both jaws after surgical osteotomies. For more than 50 years, the planning of surgical repositioning of both jaws has been entrusted to conventional articulator model surgery (CAMS) with the combined use of lateral and postero/anterior cephalograms, orthopantomography, model casts, facial bows, semi-adjustable articulator, construction of resin splints. Although these methods are effective, they have some limitations, especially when complex cases with severe dento-facial deformities are present [22].

With the advent of 3D imaging technologies (cone beam computed tomography – CBCT), computer-aided design and manufacturing (CAD/CAM) and computer-aided surgical simulation (CASS) technologies in the orthognathic surgical field, the paradigm shifted by CAMS planning to virtual surgical planning (VSP) [23].

VSP allows to plan the surgical therapy with lesser laboratory and decisional steps, plan different surgical simulations to compare, preview the skeletal effects on soft and hard tissues with good reproducibility, and create surgical splint with 3D printers in a reduced working time [24-26].

Although these major advantages, there are some considerations that must be taken in mind; as a matter of fact, there could be limitations and imprecision inherent in the software with superficial rendering errors or less propensity of surgeons to face these innovations. In order to weigh both advantages and disadvantages mentioned above, the accuracy of this new digital working flow, that is to say, VSP has to be tested.

The aim of this study is to test the accuracy of VSP performed with DDS-PRO professional software (DDS-PRO, Czestochowa, Poland) in a group of Class III surgical cases treated by bimaxillary orthognathic surgery, comparing VSP planning and post-operative CBCT scans.

Material and Methods

Study Design and Sample

This retrospective study analyzed 23 patients (9 males and 14 females; mean age 24.1 ± 7.0) who had undergone orthognathic surgery for skeletal Class III malocclusion in the Department of Maxillo-Facial Surgery of San Bortolo Hospital of Vicenza, Italy, in a period from February 2018 to November 2019.

Inclusion criteria for retrospective patient selection were severe skeletal Class III malocclusion (ANB<3°, Wits<3mm and OVJ<3mm) with any divergence or skeletal asymmetry limitations; patients older than 17 years old; bimaxillary orthognathic surgery of skeletal Class III malocclusion; presence of pre-surgery CBCT scans with the execution of VSP with DDS-PRO professional software; presence of post-surgery CBCT scans performed no more than 1 month after orthognathic surgery; no craniofacial syndromes or congenital dento-facial deformities.

Orthognathic surgeries were performed by the same expert maxillo-facial surgeon (UB), and they comprised both Le Fort I maxillary osteotomy according to Bell [27] and bilateral sagittal split mandibular osteotomy (BSSO).

Descriptions of Methods

In total, 46 CBCTs scans were obtained, of which 23 pre- and 23 post-surgery CBCT scans. They were executed in the radiological center Novarad of Vicenza (Italy) with NewTom 5G XL Extra Vision machine (Newtom CEFLA SC, Imola, Italy).

This machine used the SafeBeamTM technology to reduce x-ray emission according to tissue characteristics of the patients with a dose-volume product comprising between 197.16 mGyCm3 a 260.78 mGyCm3. The beam voltage is set at 110kV with an amperage comprising between 7 and 11 mA. The x-rays emission mode is pulsed for a time of 5.4s.

The 23 pre-surgery CBCTs were used to perform VSPs with DDS-PRO professional software. Due to the fact that these could not be exported in an open format but only in .o3 extension, i.e., a format of property of DDS-PRO software (DDS-PRO, Czestochowa, Poland), authors imported the post-surgical CBCTs into the same software to make measures and to compare them. A substantial difference is the poor accuracy of post-surgical CBCTs regarding dental arches since post-surgical intraoral scans were not acquired.

Before to perform a direct comparison, each CBCT scan has been oriented in the space according to Natural Head Position (NHP (Arnett) using "orientation" tool. References points for this procedure are four:

- The lowest and the most anterior point of left orbital rim (left Orbitale point or lO point).
- The highest point of temporozygomatic suture bilaterally (left and right temporo/zygomatic points or lTZ and rTZ point).
- Nasion point or Na point (the most anterior and medial point of frontonasal suture).

Cranium's orientation allowed to set the Frankfort Horizontal plan (passing by TZ and lO points) of each cranium, lying to horizontal plane reference (xz-plane) of the software (Figure 1). After this, both linear and angular manuals measures are performed according to 10 landmarks and 7 planes. Landmarks used are:

- A point: the most retrusive mid-point of anterior concavity of maxillary bone.
- B point: the most retrusive mid-point of anterior concavity of mandibular bone.
- U1 point: upper interincisal mid-point of maxillary central incisors.
- L1 point: upper interincisal mid-point of mandibular central incisors.
- MBC 1.6 point: mesio-buccal cusp of 1.6 tooth.
- MBC 2.6 point: mesio-buccal cusp of 2.6 tooth.
- MBC 3.6 point: mesio-buccal cusp of 3.6 tooth.

• MBC 4.6 point: mesio-buccal cusp of 4.6 tooth.

• rMF point: right mental foramen point.

• lMF point: left mental foramen point (Figure 2).

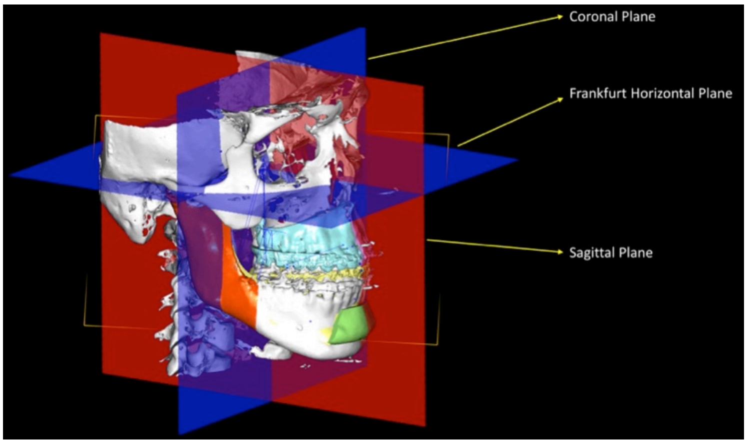

Figure 1. Orientation of cranium in the space. Horizontal plane corresponds to Frankfurt plane (passing for both left and right ZT).

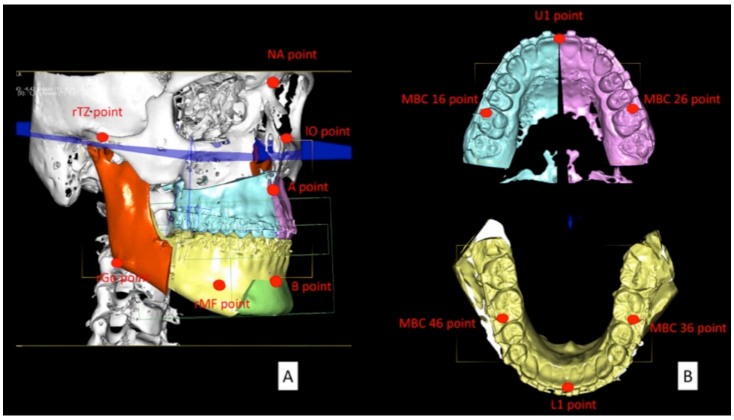

Figure 2. Graphical representation of skeletal (A) and dental landmarks (B).

Planes used are:

• XZ-plane: horizontal plane corresponding to Frankfurt plane set in the orientation phase.

• YZ-plane: sagittal plane (perpendicular to horizontal plane passing by Point Na).

• XY-plane: coronal plane (perpendicular to horizontal plane passing by LZG and RZG point).

• CBP: cranial base plane passing by Nasion point and bilateral Basion points. They are both 2mm laterally shifted points respect to the mid-point Basion (Ba) on the anterior rim of the magnum. Nasion point is the most anterior and medial point of frontonasal suture (Figure 1).

• UOP: upper occlusal plane passing by the midpoint in the marginal ridges of both maxillary central incisors and the point in the disto-buccal cusp of both left and right maxillary first molar.

• LOP: lower occlusal plane passing by the midpoint in the marginal ridge of mandibular central incisors and the point in the disto-buccal cusp of both left and right mandibular first molar.

• MP: mandibular plane passing for both left and right gonion points and the menton point. Menton point (Me) is defined as the lowest point of mental symphysis bone. Bilateral gonion points (rGo and lGo) are constructions points with the intersection of two lines tangent to the posterior margin of mandibular ramus and the lower margin of the mandibular body (Figure 3).

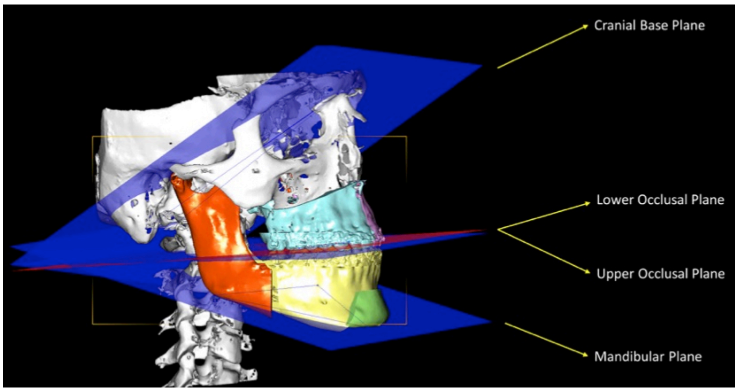

Figure 3. Graphical representation of four construction planes. CBS is considered a reference plane.

The first four planes are used as a reference plane to detect deviations of UOP, LOP and MP plane calculating the roll, pitch and yaw (Figure 4) and to CBP, which is a stable structure not modified by double jaws orthognathic surgery.

The coordinates of each single point (x, y, z) in the three planes of space were then obtained using the "reference point measurement" tool. Also, the angular measures between planes above mentioned were obtained with the use of "goniometer" tool. Deviations are considered clinically acceptable if they are within 2mm for linear and 4° for angular measure [23].

One month after taking the measures, 11 subjects were randomly selected and the measurements were repeated. Despite the possibility to superimpose the two scans, it could not be allowed a direct comparison of the two volumes due to limitations of this software; therefore, linear and angular measures were performed with the above-mentioned tools.

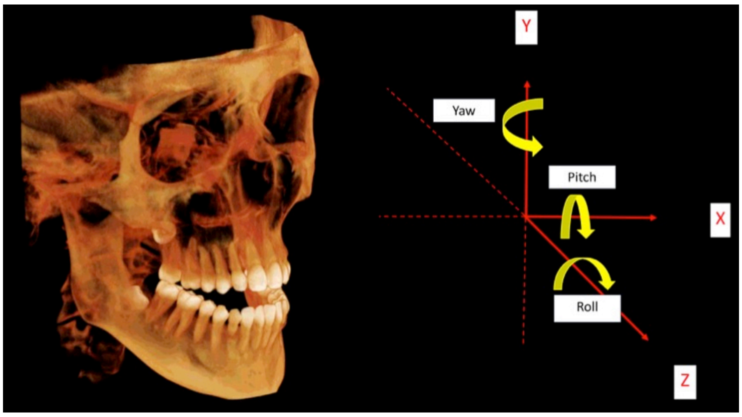

Figure 4. Graphical representation of roll, pitch and yaw. Roll is turning around Z-axis, pitch around X-axis and yaw around Y-axis.

Statistical Analysis

All data were analyzed using R 3.5 software (R Foundation for Statistical Computing, Vienna, Austria) [28]. First, for each landmark identified, deviations between VSP and post-surgical CBCT scans were measured both like absolute linear value or relative value to each plan, obtaining respectively mean values confidence intervals (95%). Then, a paired t-test was used to calculate the mean differences for each deviation with the relative 95% confidence interval (p-value <0.05 considered significant). The same has been done for angular measurements.

The confidence intervals include plausible values for the differences between the two measures compared, and thus we need to identify statistical significant differences. When the confidence intervals do not overlap with each other, a significant statistical difference could be affirmed; on the other hand, if there is an overlapping of the two groups of values, also partially, this difference cannot be affirmed to be statistically significant. In partial overlapping, this difference could be considered clinically acceptable if most parts of values intersect each other.

In the event that the interval intersects the cut-off line, statistical significance cannot be affirmed, but it can still be clinically acceptable if a large part of it (therefore, most of the values) should be below the threshold. The confidence interval is directly influenced by the sample: the higher the number, the narrower the interval. The method error was quantified by calculating the Intra-Class Correlation (ICC) between the initial measures and those repeated at 1 month, on a subgroup (2 linear and 2 angular) for 11 randomly selected subjects. The ICC calculated was excellent (coefficient 0.99); therefore, reproducibility and accuracy of the measures is assumed.

Results

Mean linear variations between VSP and post-surgical CBCTs are reported in Table 1 as absolute deviations and respect to each plane. Statistically significant differences between the planned and the real are marked with asterisk (*).

For the absolute deviations, all the linear measures overcome the 2 mm threshold value of clinical acceptability, with a mean discrepancy of 4.57 mm (3.79-9.87), and these differences are always statistical significance. About x-linear dimension, all measures are within threshold value except for MBC point of all the first molars. The mean value registered is 2.53 mm (1.79-3.26), and the statistical significance is reached four times. About y-linear dimension, all measures are within threshold value except for B point (2.21 mm; 1.48-2.94) and MBC 26 (3.19 mm; 0.00-7.98). The mean value registered is 1.7 mm (1.21-2.19) and the statistical significance is reached six times.

Table 1. Linear deviations (mm) measured as absolute deviations and referred to X, Y and Z-linear dimension.

Reference Point	Absolute Deviation Mean (mm)	Absolute Deviation CI (95%) (mm)	X-linear Dimension Mean (mm)	X-linear Dimension CI (95%) (mm)	Y-linear Dimension Mean (mm)	Y-linear Dimension CI (95%) (mm)	Z-linear Dimension Mean (mm)	Z-linear Dimension CI (95%) (mm)
A	3.43*	2,52-4.34*	1.1*	0.71-1.50*	1.94	0.98-2.90	1.82	1.15-2.48
B	3.97*	3.25-4.68*	1.52	0.90-2.13	2.21	1.48-2.94	2.06	1.41-2.72
UI	3.12*	2.35-3.89*	0.96*	0.59-1.32*	1.41*	0.97-1.85*	2.13	1.29-2.97
LI	3.91*	3.00-4.82*	0.98*	0.54-1.43*	1.95	1.14-2.75	2.52	1.63-3.41
RFM	3.48*	2.80-4.16*	1.5	0.96-2.05	1.47*	0.99-1.95*	2.17	1.46-2.88
LFM	3.68*	2.81-4.55*	1.6	0.80-2.40	1.36*	0.77-1.95*	2.37	1.70-3.05
MBC 16	3.6*	2.66-4.54*	2.44	1.56-3.32	0.9*	0.58-1.22*	1.89	1.17-2.60
MBC 26	8.64*	2.72-14.57*	4.9	0.64-9.16	3.19	0.00-7.98	2.41	1.50-3.33
MBC 36	8.44*	2.19-14.70*	7.2	0.91-13.49	1.14*	0.70-1.57*	2.86	1.63-4.09
MBC 46	4.69*	3.67-5.72*	3.42*	2.40-4.44*	1,.32*	0.89-1.75*	2.27	1.57-2.98
Total	4.57*	3.79-9.87*	2.53	1.79-3.26	1.7	1.21-2.19	2.25*	2.01-2.49*

Each measure is described by its own mean value and its confidence interval (95%); Significant statistical differences between VSP and post-surgical CBCT scans is marked with an asterisk.

About z-linear dimension, all the mean values are beyond the 2 mm threshold value except for A point (1.82 mm; 1.15-2.82) and MBC 16 (1.89 mm; 1.17-2.60). Thus, the mean value registered is 2.25 mm (2.01-2.49) and the statistical significance is only for this latter value (Figure 5).

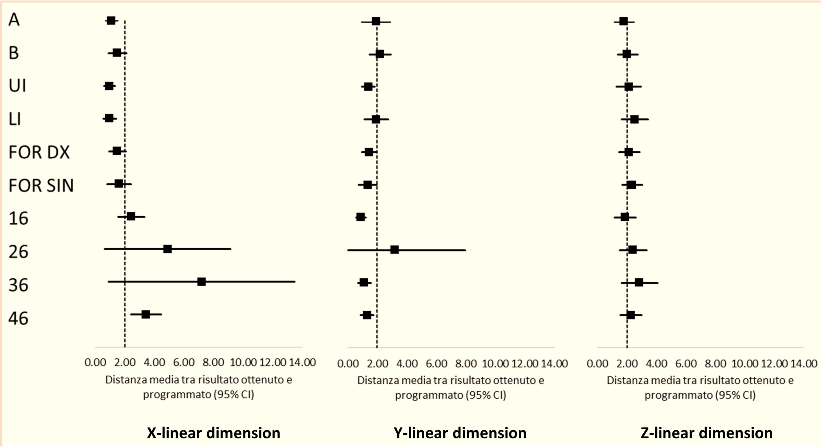

Figure 5. Graphical representation of mean linear values and their confidence interval (95%) according to 2 mm threshold value.

Mean angular deviations between VSP and post-surgical CBCT scans are all within 4° threshold value of clinical acceptability, although all comparisons reach the statistical significance except for UOP^MP comparison (Table 2).

Table 2. Angular deviations (°) of UOP, LOP and MP planes referred to CBP. Also roll, pitch and yaw deviations are recorded.

	Reference Planes							
Planes	Roll		Pitch		Yaw		CBP	
	Mean (°)	CI (95%) (mm)	Mean (°)	CI (95%) (mm)	Mean (°)	CI (95%) (mm)	Mean (°)	CI (95%) (mm)
UOP	0.70*	0.58-0.87*	1.67*	1.07-2.27*	1.71*	1.04-2.37*	2.23*	1.45-3.02*
LOP	0.64*	0.23-1.05*	1.84*	1.04-2.64*	1.76*	0.98-2.54*	2.44*	1.49-3.39*
MP	0.86*	0.52-1.20*	2.81*	1.86-3.77*	2.79*	1.86-3.72*	2.60*	1.71-3.48*
UOP^MP	3.61 (2.54–4.77)							

Each measure is described by its own mean value and its confidence interval (95%). *Significant statistical differences between VSP and post-surgical CBCT scans are marked with an asterisk.

The highest discrepancy value is recorded between UOP and MP, with the mean deviation value of 3.61° (2.54-4.77), although the latter is within the clinical acceptability threshold and it does not reach a statistical significance (Figure 6).

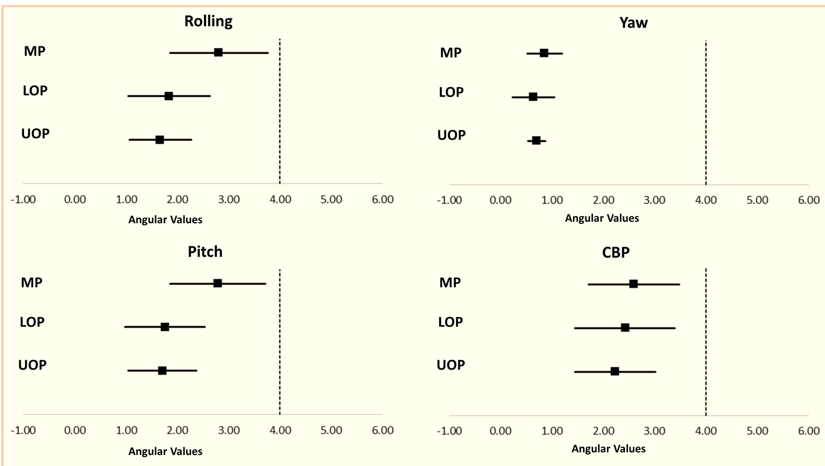

Figure 6. Graphical representation of angular linear values and their confidence interval (95%) according to 4° threshold value.

Discussion

This retrospective study aims to investigate the accuracy of VSP for orthognathic surgery in Class III surgical cases. Class III malocclusions could be particularly socially disabling, especially when skeletal sagittal discrepancy is severe and it is perceived as a problem by the patient [29]; for this reason, Class III surgical treatment is the most common among the surgical orthognathic approaches [30]. Therefore, the study of accuracy of VSP in these cases is of particular interest.

Comparisons have been made between VSP and 1-month post-surgical CBCT scans to avoid orthodontic mechanics, which can hide and underestimate the surgical movement of skeletal bases. After this direct comparison, we set a threshold value of both linear and angular deviation to register what variations could be considered acceptable under clinical point of view. These threshold values are set at 2 mm for linear values and 4° for angular values and they were proposed by Xia et al. [23] and Marchetti et al. [31].

The first authors to propose a pilot study to overcome conventional model surgery planning were Xia et al. [23], who performed a pilot study to assess the accuracy of CASS, obtaining mean deviations of 0.9 mm and 1.7°. After this, others authors checked the accuracy of these 3D planning systems, always noticing a good accuracy and reproducibility of the method [31-33]. Finally, Mazzoni et al. [34] studied in a group of 10 patients a new intra-operating guided procedure for jaws repositioning, funding good accuracy.

Hsu et al. were the first authors to investigate accuracy referring to each surgical plane (XY, YZ and XZ planes), reporting a good reproducibility for all the linear measures investigated, encouraging at the same time the use of a CAD-template to perform genioplasty [35].

Encouraging results have been found by other authors [22,36], although Ritto et al. [22] and Tonin et al. [36] investigated the only accuracy of maxillary position. Heufelder et al. [37] and Kim et al. [38] confirmed previous investigations, although they used a waferless technique with a prototyped guide for osteotomy lines and drilling holes for fixation, and customized prototyped miniplates for repositioning and stabilizing the maxillary jaw, reducing thus vertical errors.

In our study, the good reproducibility of VSP is tested, although we experienced higher deviation values concerning threshold linear value, especially for absolute deviations and for dento-alveolar landmarks. About the x-linear dimension, the mean discrepancy value (2.53mm; 1.79-3.26) is slightly higher of 2mm cut-off value, but all skeletal deviations are lesser than 2 mm to a higher extent. The worst values are registered for dental values.

The accuracy on Y-linear dimension is good with a mean average value of 1.7 mm (1.21-2.19) and with only two deviations over 2 mm (B and MBC 26), while on Z-linear dimension, the average deviation value is beyond 2 mm (2.25; 2.01-2.49) with only two deviations under the cut-off linear value. These findings agree with Heufelder et al. [37], who registered less accuracy in Z-linear dimension with respect to Y-linear dimension.

According to our study, it can be partially explained by two phenomena. The first is that surgical setback of mandible acts inevitably on the condyle with a subsequent forward movement that usually occurred in the post-operative period. Another element is attributable to the inclination of maxillary osteotomy line that could affect the anteroposterior displacement of the mobilized segment. The more vertical is the cut, greater is the limitation compared to what was programmed with the wafer.

Regarding the angular discrepancies, our study shows that all mean deviations is within 4° with values ranging from 0.64 mm (0.23-1.05), between UOP and sagittal plane, to 3.61 mm (2.54–4.77), between UOP and PM. In detail, the greater accuracy is for the roll, followed by yaw and pitch.

Our findings agree with other studies, which register a good overall accuracy, but with greater discrepancies detected for pitch and yaw [35,36,39], and this could be due to reduced fitting of surgical intermediate splints [39,40].

An overview of these results shows a better accuracy for both linear respect to angular measures and for skeletal respect to dento-alveolar landmarks. The first aspect could be measuring procedures that enable better identification of planes compared to point-like landmarks in the DDS-PRO software. The second aspect could be fully explained by the less accuracy in reproducing dento-alveolar structures, especially in the post-surgical CBCTs, due to both poor superficial rendering and the fact that post-surgical intraoral scans were not performed and superimposed in post-surgical CBCTs.

This study, although well-conducting, seems to show some limitations. First of all, post-surgical intraoral scansion should be performed to increase superficial details of dento-alveolar component; while considering measures procedure, DDS-PRO software does not allow direct superimpositions and the use of complexes algorithms, should guarantee reproducibility and constancy for measures. According to the above-mentioned limits, further future studies are mandatories.

Conclusion

VSP could be considered an accurate method to plan orthognathic surgery in surgical Class III cases, although some imprecisions have been detected. The accuracy is optimal for angular and good for linear investigations, although further studies should be performed overcoming some abovementioned limitations.

Authors' Contributions

MP	https://orcid.org/0000-0001-6198-3053	Conceptualization, Methodology, Formal Analysis, Investigation and Writing - Original Draft.
GLF	---	Writing - Review and Editing.
PA	https://orcid.org/0000-0002-4020-5065	Conceptualization and Writing - Review and Editing.
ADG	---	Writing - Review and Editing.
UB	---	Writing - Review and Editing.
FC	https://orcid.org/0000-0002-4641-2196	Conceptualization and Writing - Review and Editing.

All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.

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None.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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